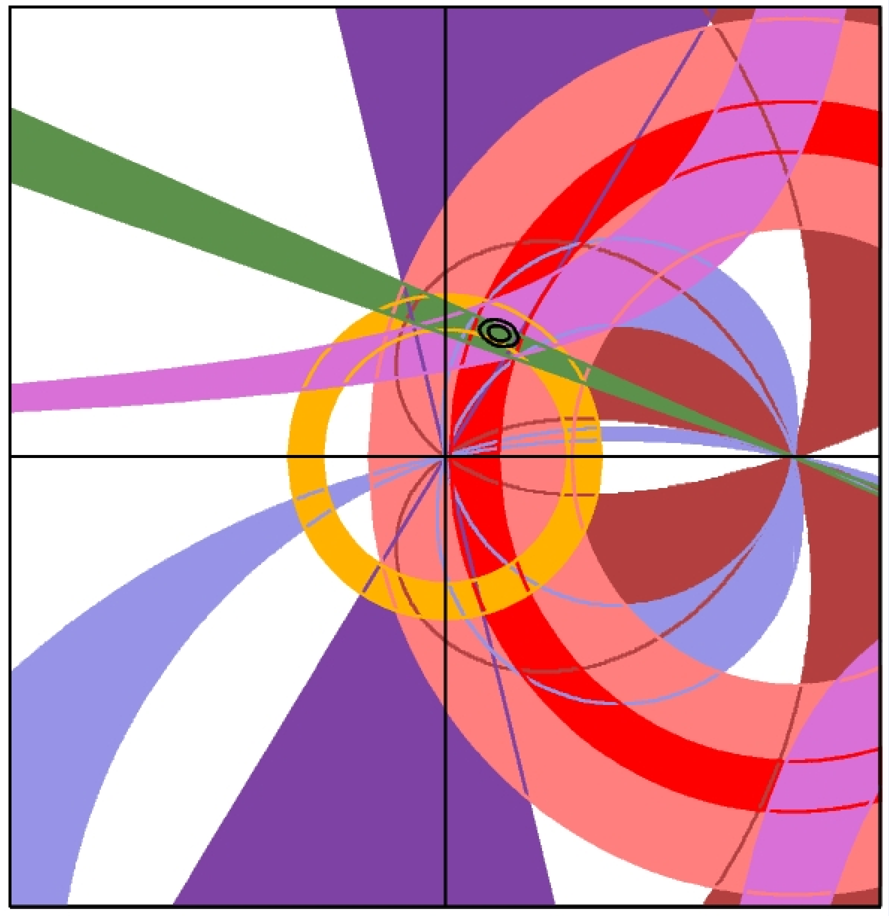
State of the CKM picture and some thoughts on perspectives



Marcella Bona

Queen Mary,
University of London

Tau-Charm 2013
La Biodola
Isola d'Elba, Italia
May 29th, 2013

unitarity Triangle analysis in the SM

- SM UT analysis:
  - provide the best determination of CKM parameters
  - test the consistency of the SM ("*direct*" vs "*indirect*" determinations)
  - provide predictions for SM observables
  - exploits $\Delta F=2$ transitions with down quarks

.. and beyond

- NP UT analysis:
  - model-independent analysis
  - provides limit on the allowed deviations from the SM
  - NP scale analysis

www.utfit.org

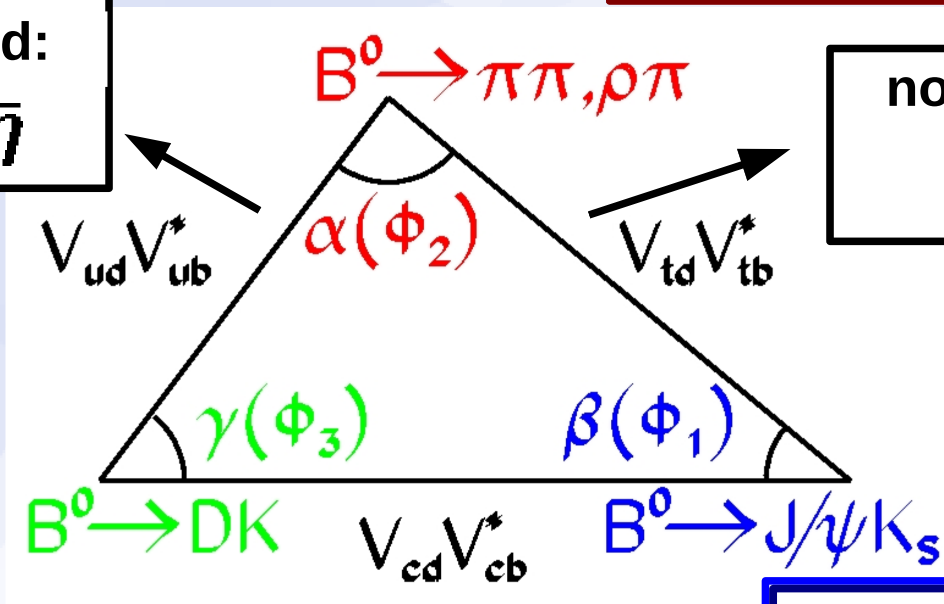
A. Bevan, M.B., M. Ciuchini, D. Derkach,
E. Franco, V. Lubicz, G. Martinelli, F. Parodi,
M. Pierini, C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

CKM matrix and Unitarity Triangle

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\overline{\rho}-i\overline{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\overline{\rho}-i\overline{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

normalized:

$\bar{\rho} + i\bar{\eta}$



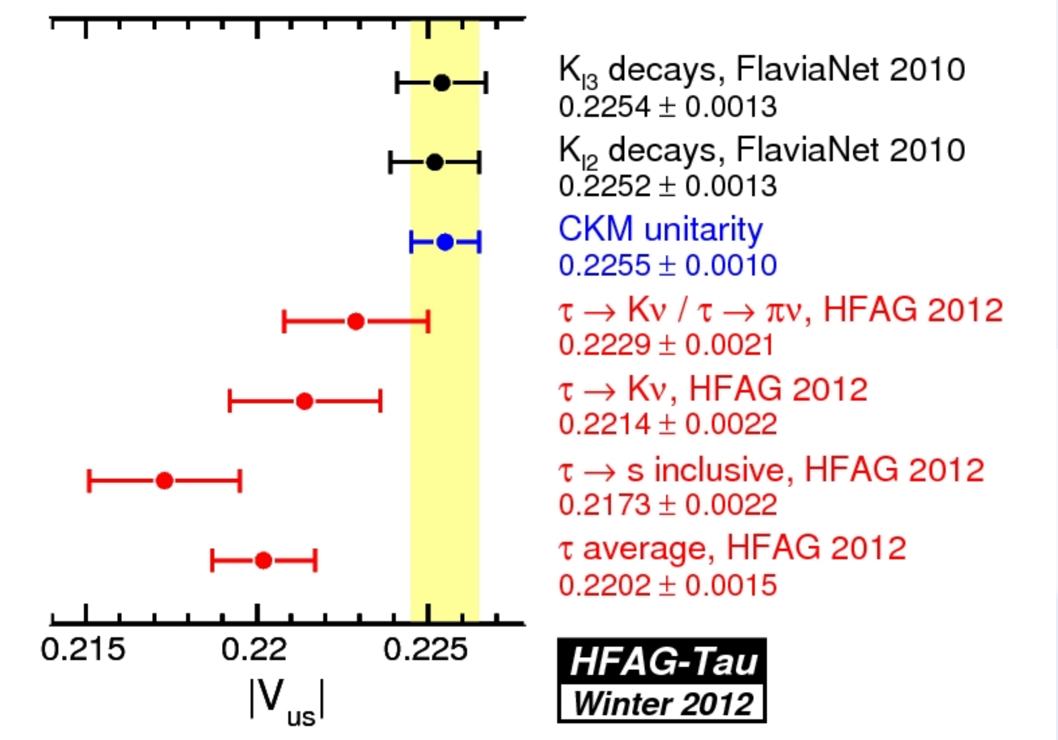
normalized:

CKM matrix and Unitarity Triangle

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar\rho-i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

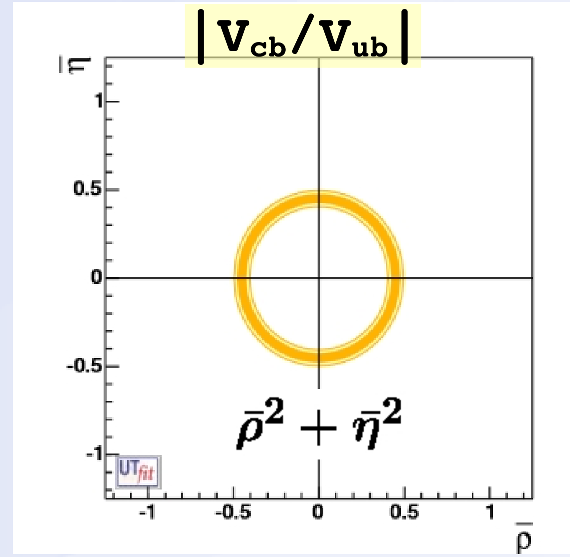
0.2254 ± 0.0009
[Flavianet arXiv:1011.4408]

$\tau \rightarrow K\pi\nu$, K_{l3}
$\tau \rightarrow K(\pi)\nu$, P_{l2}
$\tau \rightarrow \nu X$ inclusive

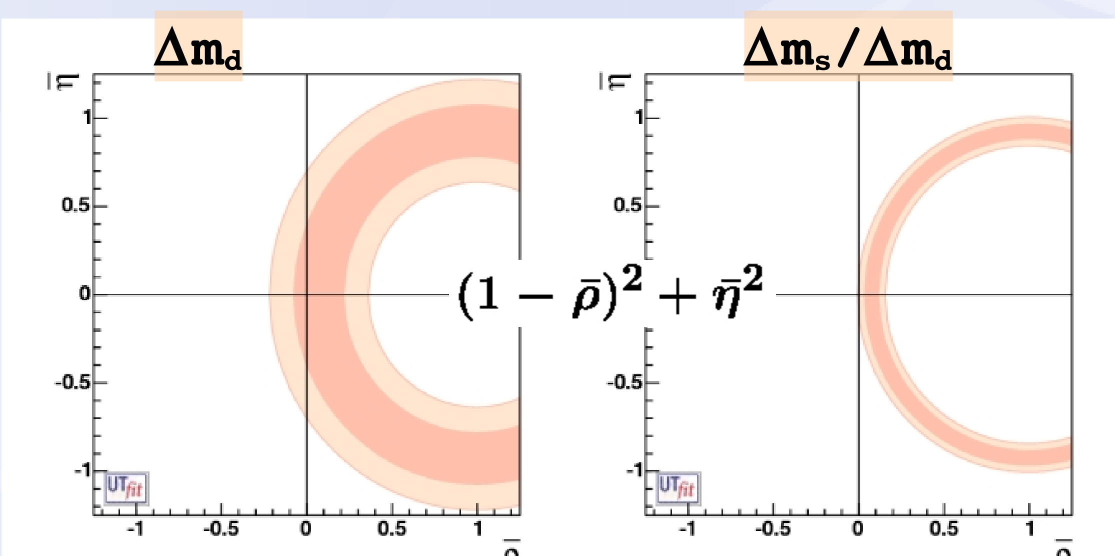


CP-conserving inputs

$|V_{ub}|/|V_{cb}| \sim R_b$ (tree-level)



B_d-B_d and B_s-B_s mixing



$\Delta m_d = (0.507 \pm 0.004)\ \mathrm{ps}^{-1}$

$\Delta m_s = (17.72 \pm 0.04)\ \mathrm{ps}^{-1}$

$$\Delta m_d \approx [(1-\rho)^2 + \eta^2] \frac{f_{B_s}^2 B_{B_s}}{\xi^2}$$

$$\Delta m_s \approx f_{B_s}^2 B_{B_s}$$

B_{B_q} and f_{B_q} from lattice QCD

V_{cb} and V_{ub}

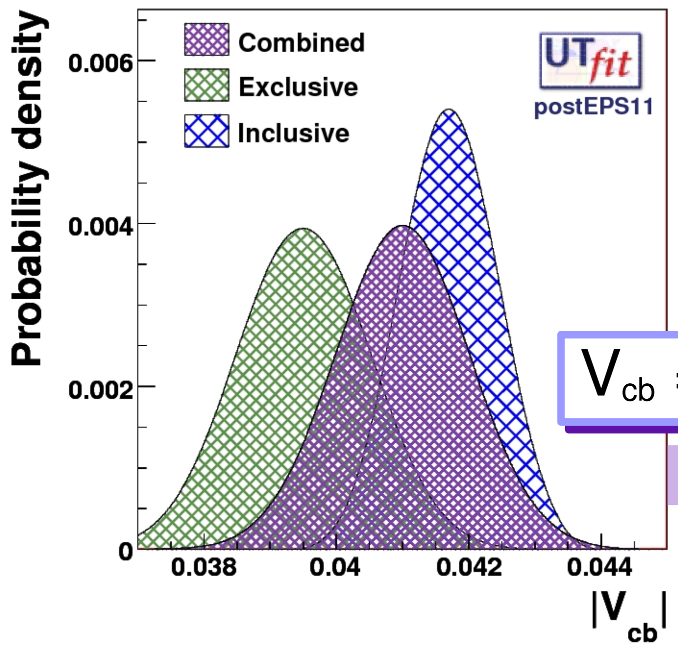
Laiho *et al*

V_{cb} *(excl)* = $(39.5 \pm 1.0)\ 10^{-3}$

HFAG

V_{cb} *(incl)* = $(41.7 \pm 0.7)\ 10^{-3}$

~1.8σ discrepancy



UTfit input value: average à la PDG

$V_{cb} = (41.0 \pm 1.0)\ 10^{-3}$

uncertainty ~ 2.4%

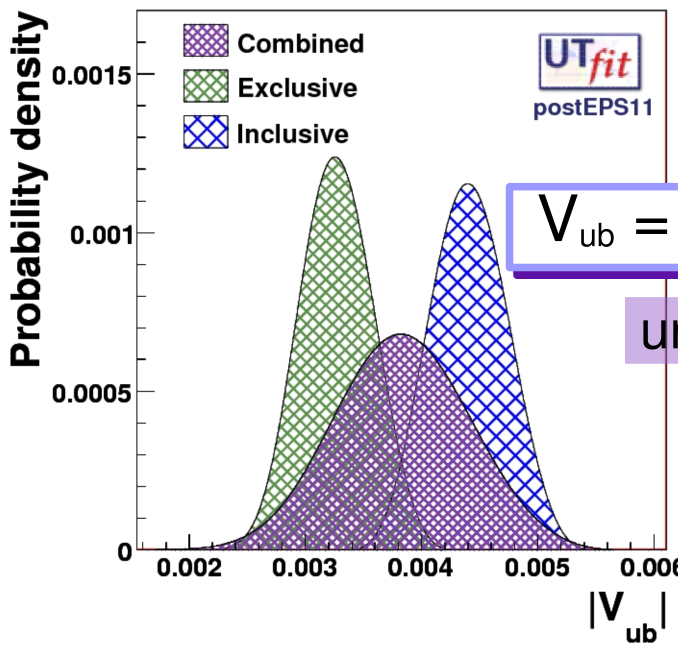
Laiho *et al*

V_{ub} *(excl)* = $(3.28 \pm 0.30)\ 10^{-3}$

UTfit from HFAG

V_{ub} *(incl)* = $(4.40 \pm 0.31)\ 10^{-3}$

~2.6σ discrepancy

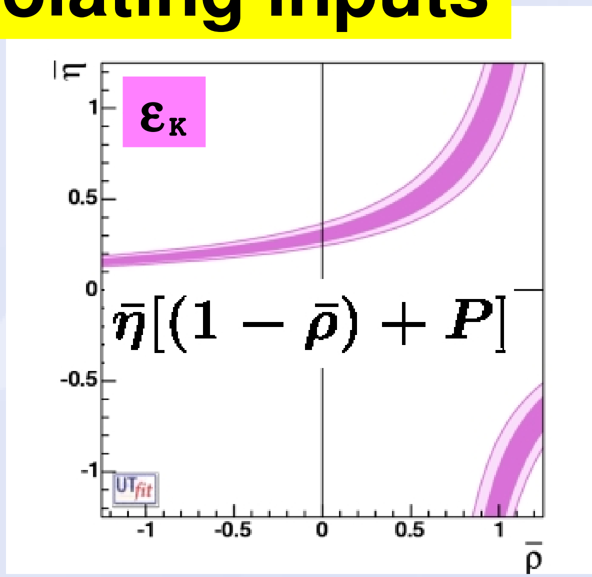


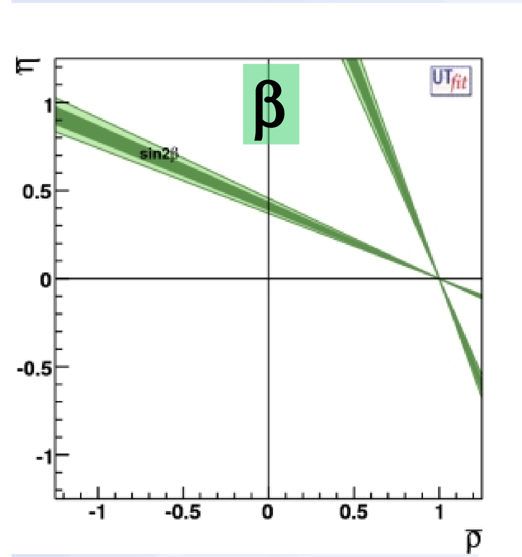
UTfit input value: average à la PDG

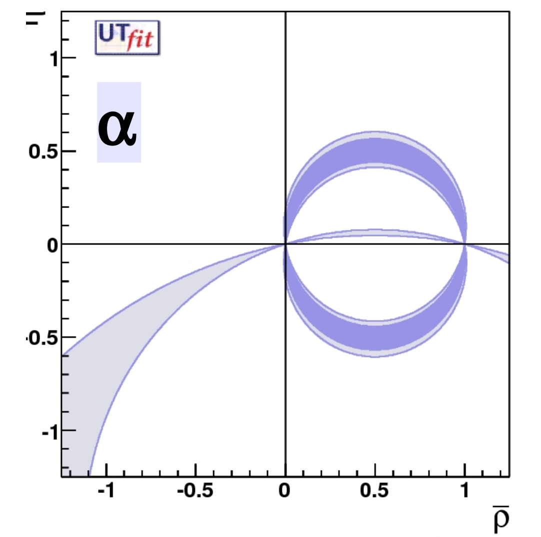
$V_{ub} = (3.82 \pm 0.56)\ 10^{-3}$

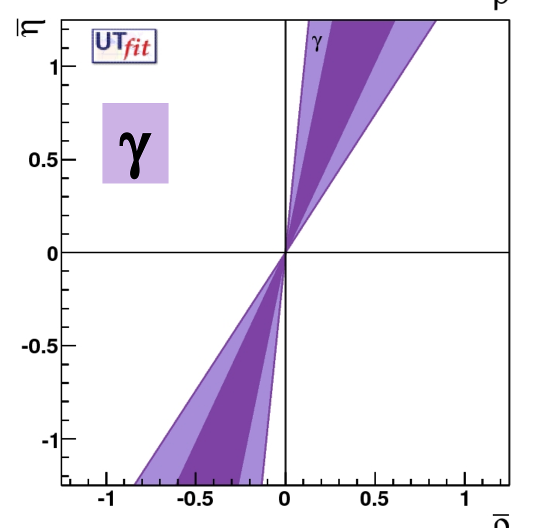
uncertainty ~ 15%

CP-violating inputs









ε_K from K-K mixing

$\rightarrow B_K = 0.730 \pm 0.030$ flag10 $N_f = 2$

sin2β from $B \rightarrow J/\psi K^0$ + theory

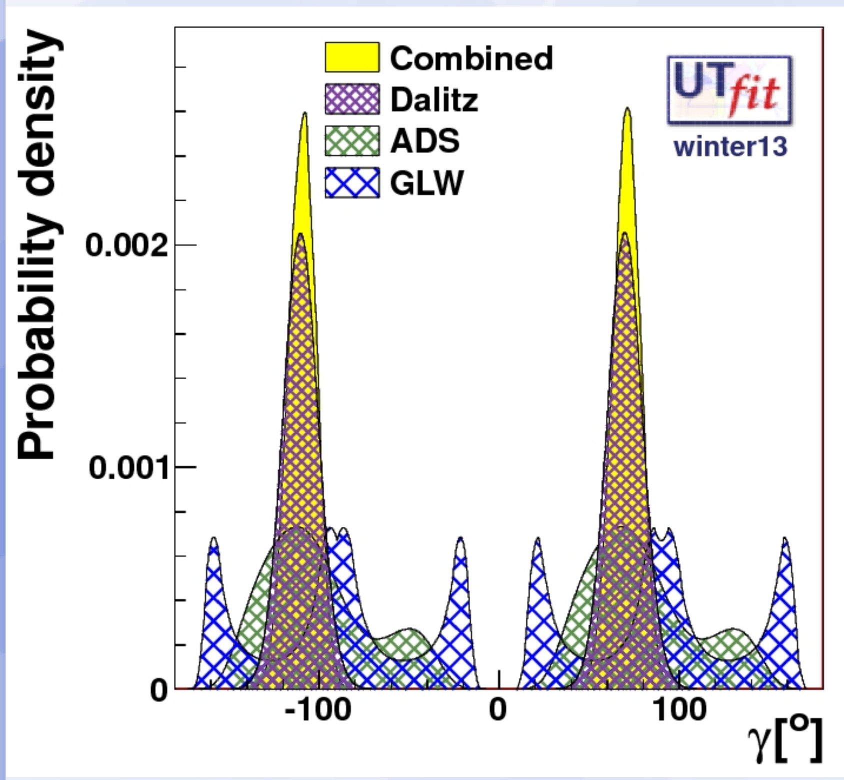
$\sin 2\beta(J/\psi K^0) = 0.680 \pm 0.023$ HFAG

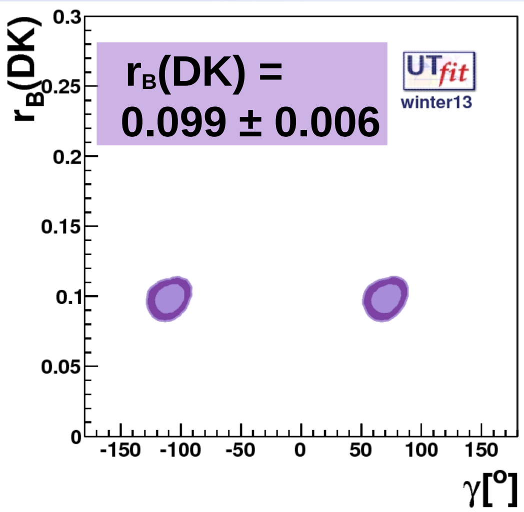
α from ππ, ρρ, πρ decays:

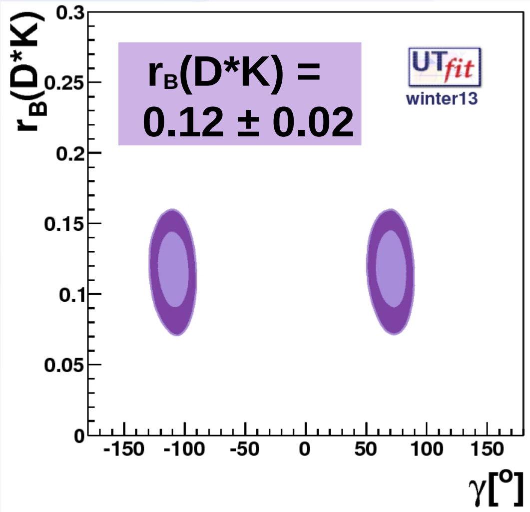
combined: $(90.9 \pm 8.0)°$

γ from $B \rightarrow DK$ decays (tree level)

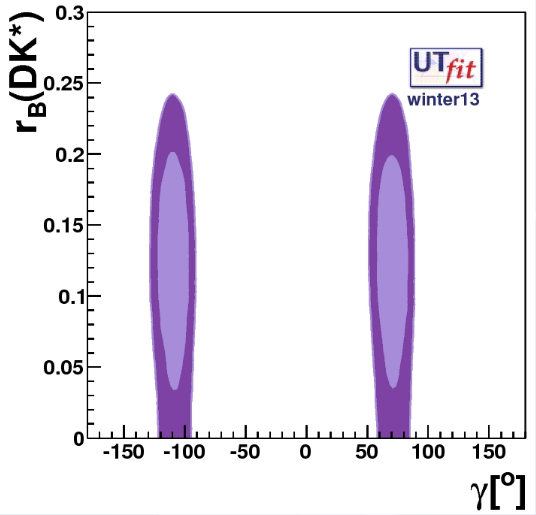
γ and DK trees







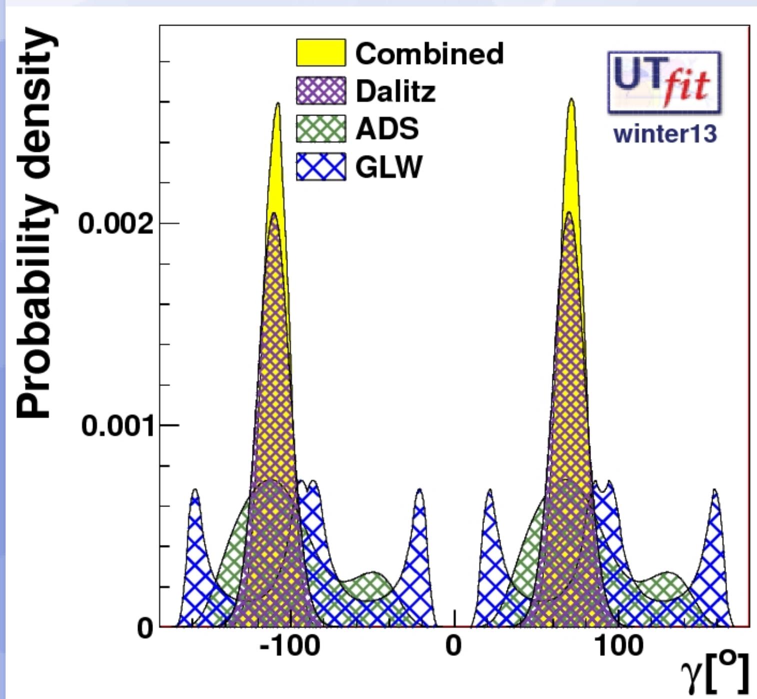
$\gamma = (70.8 \pm 7.8)^o$



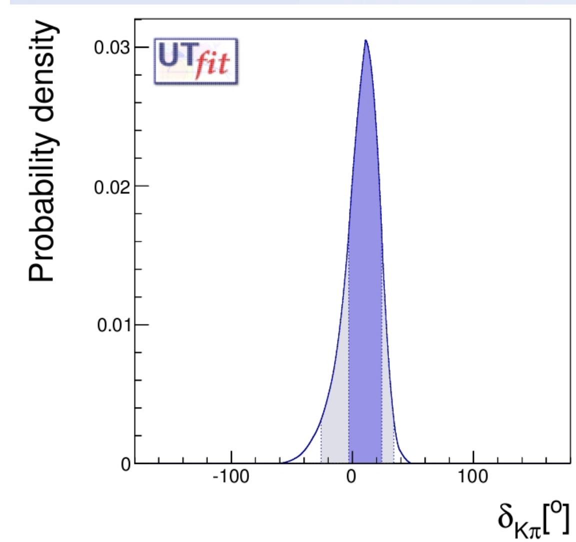
$r_B(DK^*) =$
0.12 ± 0.06

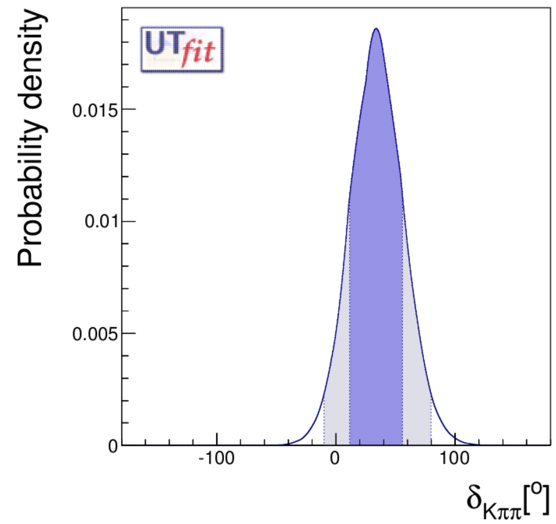
see previous session:
CP violation. strong phase. Dalitz model in charm

γ and DK trees



UTfit collaboration
JHEP 1210 (2012) 068





$\delta_{K\pi} = (11 \pm 13)^o$

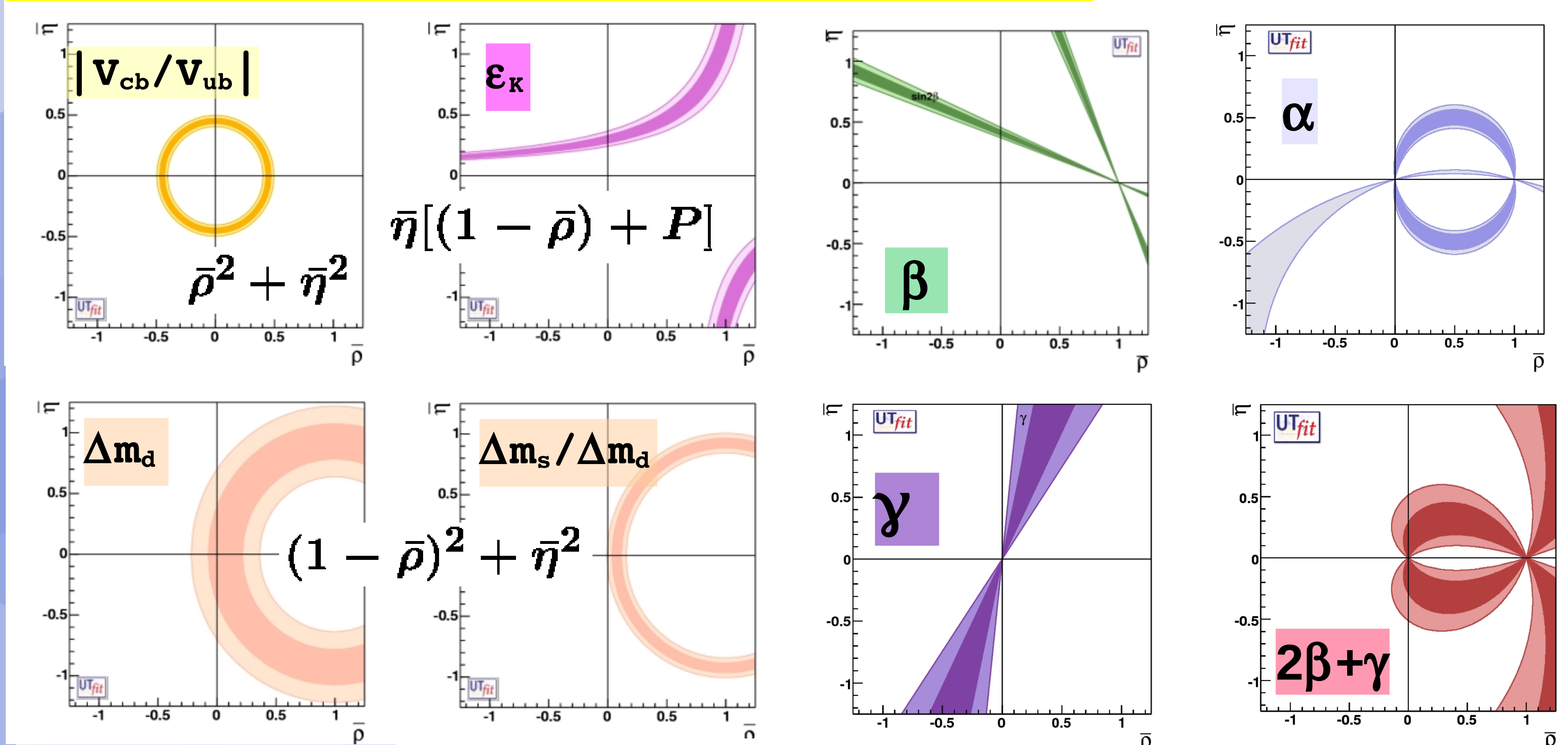
$\delta_{K\pi\pi0} = (33 \pm 21)^o$

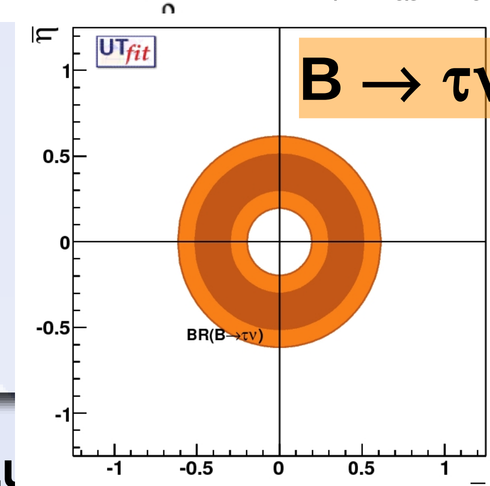
$\gamma = (70.8 \pm 7.8)^o$

See Silvestrini's talk on Monday
http://www.utfit.org/UTfit/DDbarMixing

see previous session:
CP violation. strong phase. Dalitz model in charm

Unitarity Triangle analysis in the SM:

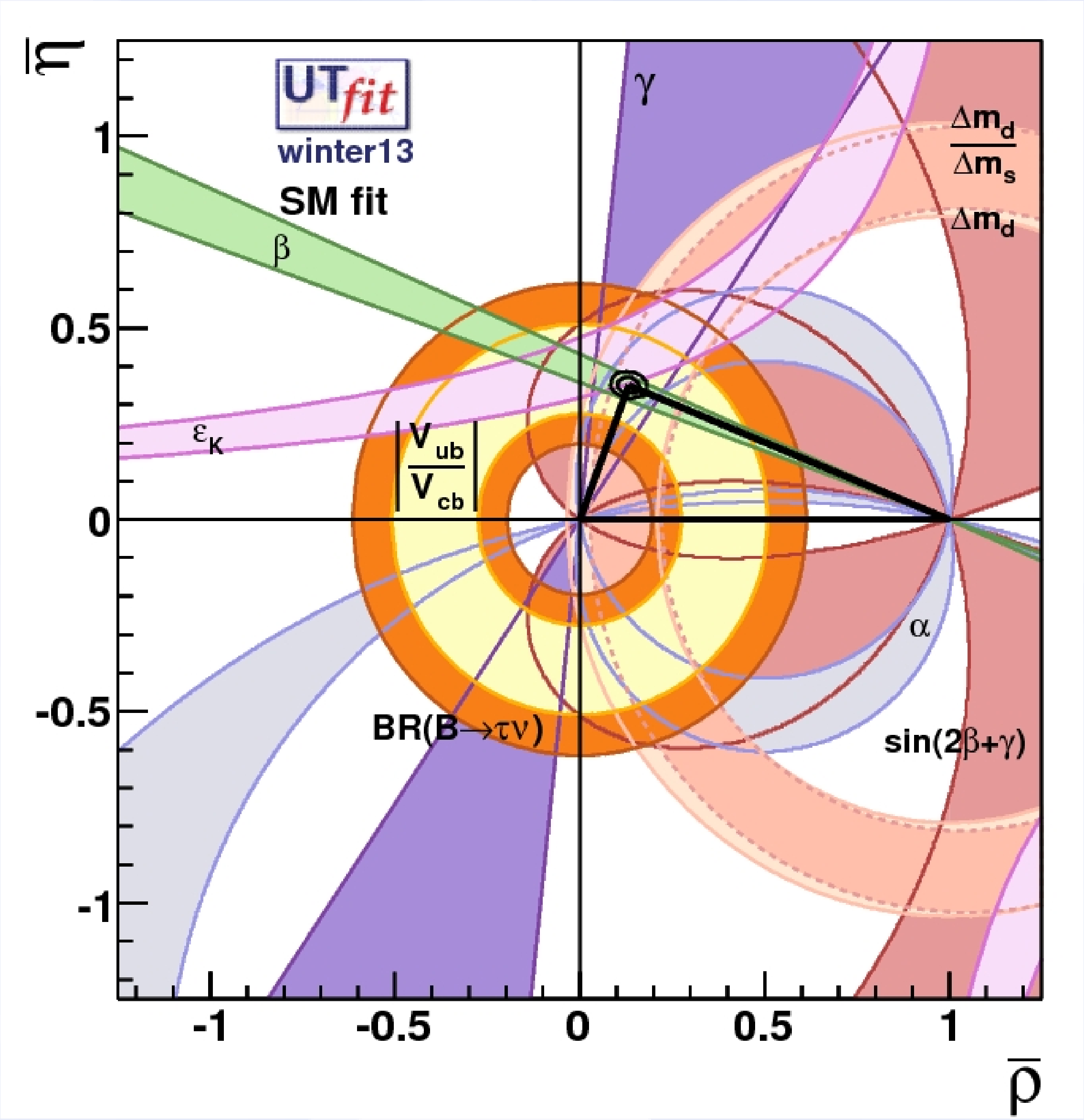




Unitarity Triangle analysis in the SM:

Observables	Accuracy
$\|V_{ub}/V_{cb}\|$	~ 15%
ε_K	~ 0.5%
Δm_d	~ 1%
$\|\Delta m_d/\Delta m_s\|$	~ 1%
$\sin 2\beta$	~ 3%
$\cos 2\beta$	~ 15%
α	~ 7%
γ	~ 10%
$BR(B \to \tau\nu)$	~ 25%

Unitarity Triangle analysis in the SM:



levels @
95% Prob

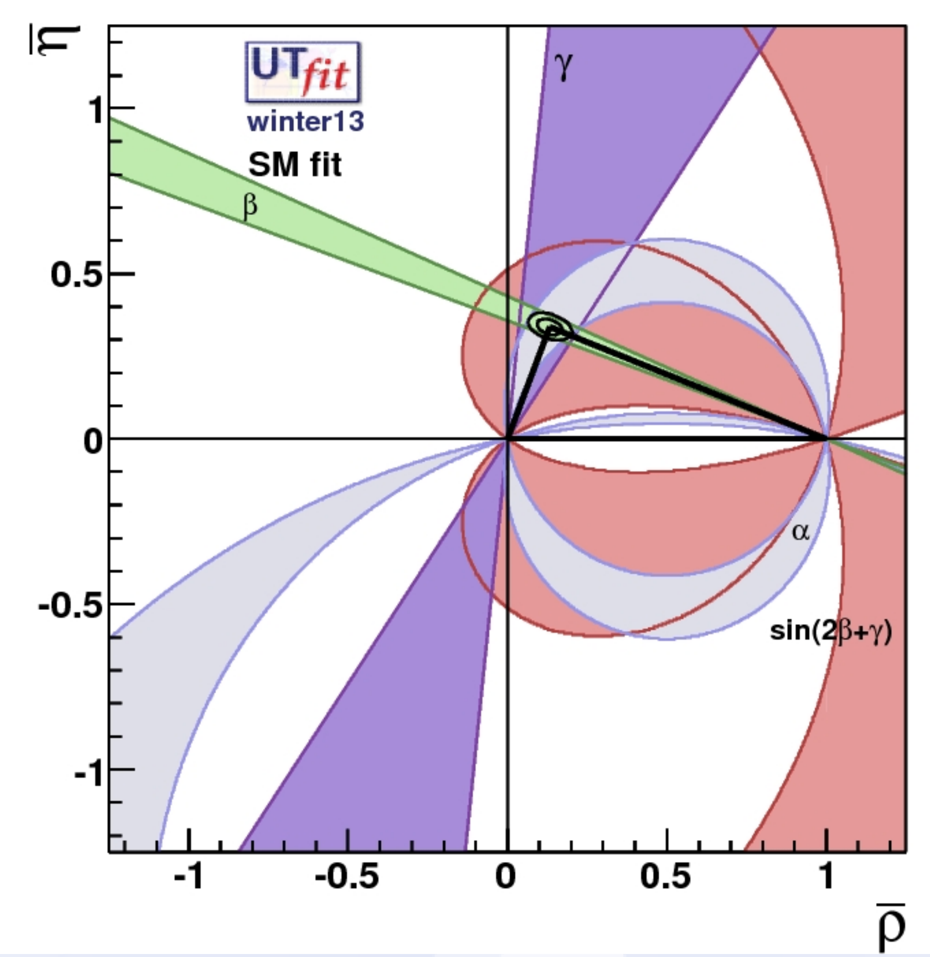
$\bar{\rho} = 0.132 \pm 0.021$

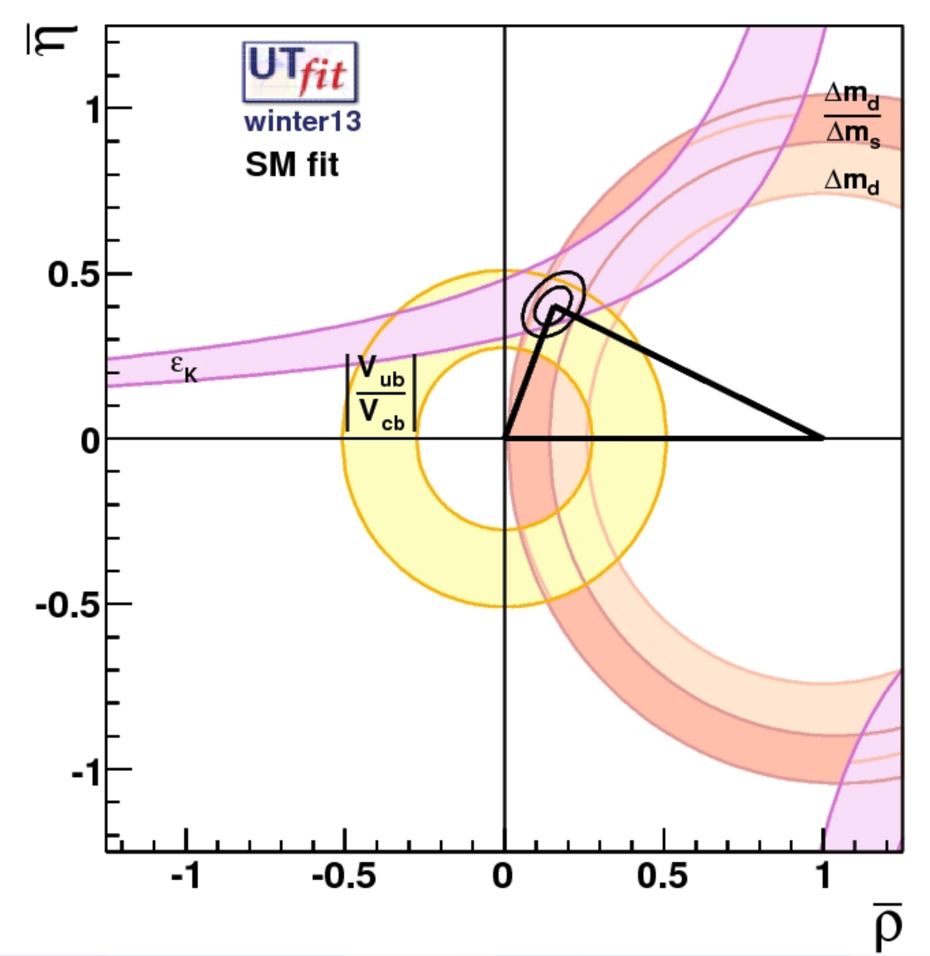
$\bar{\eta} = 0.350 \pm 0.014$

home-made
BaBar+Belle average:
$BR(B \to \tau\nu) = (0.99 \pm 0.25)\ 10^{-4}$

angles vs the others

levels @
95% Prob





$\bar{\rho} = 0.130 \pm 0.027$
$\bar{\eta} = 0.338 \pm 0.016$

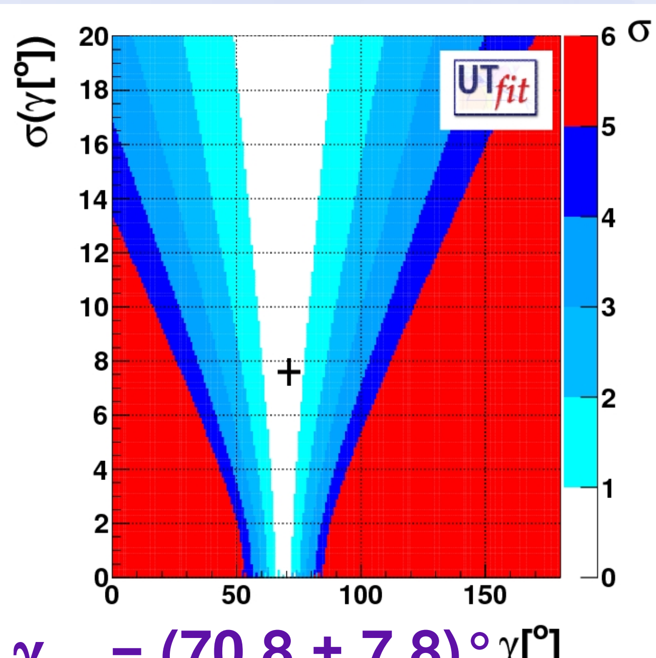
$\bar{\rho} = 0.163 \pm 0.038$
$\bar{\eta} = 0.394 \pm 0.035$

compatibility plots

A way to “measure” the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavor physics

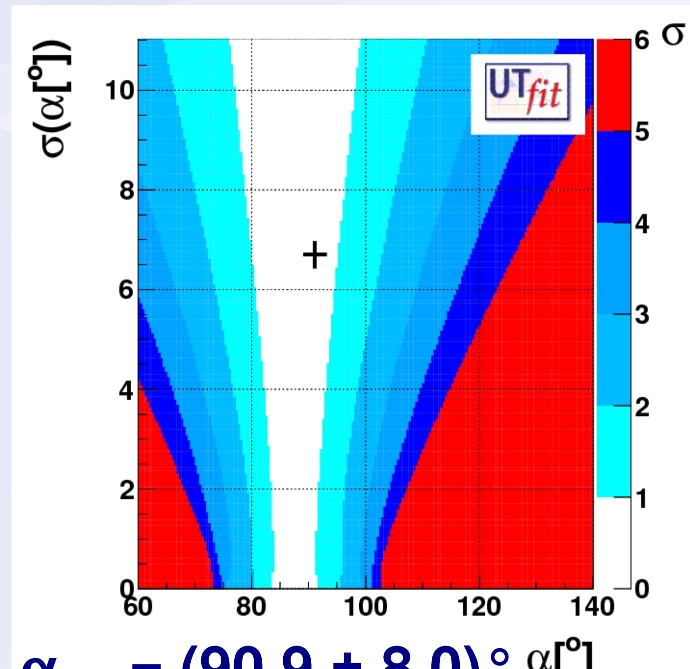
Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

The cross has the coordinates (x,y)=(central value, error) of the direct measurement



γ_{exp} = (70.8 ± 7.8)°

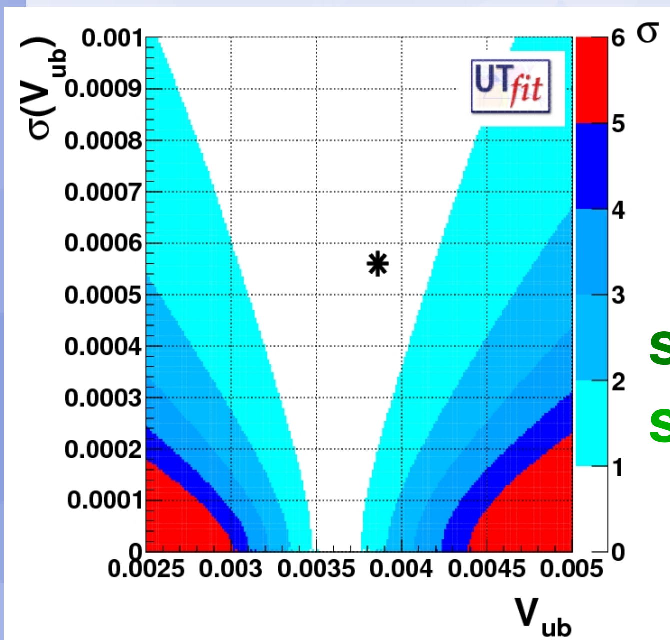
γ_{UTfit} = (68.6 ± 3.6)°



α_{exp} = (90.9 ± 8.0)°

α_{UTfit} = (87.7 ± 3.6)°

tensions (or used-to-be tensions)



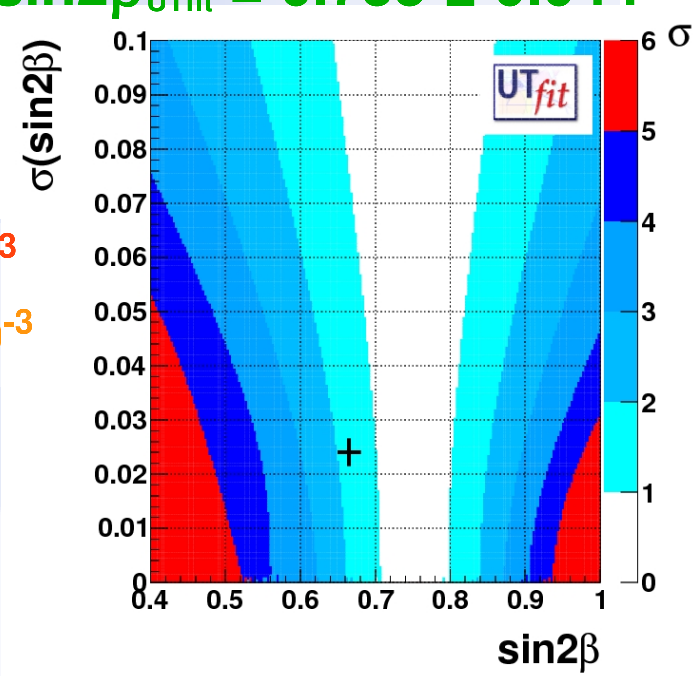
$Vub_{exp} = (3.82 \pm 0.56) \cdot 10^{-3}$

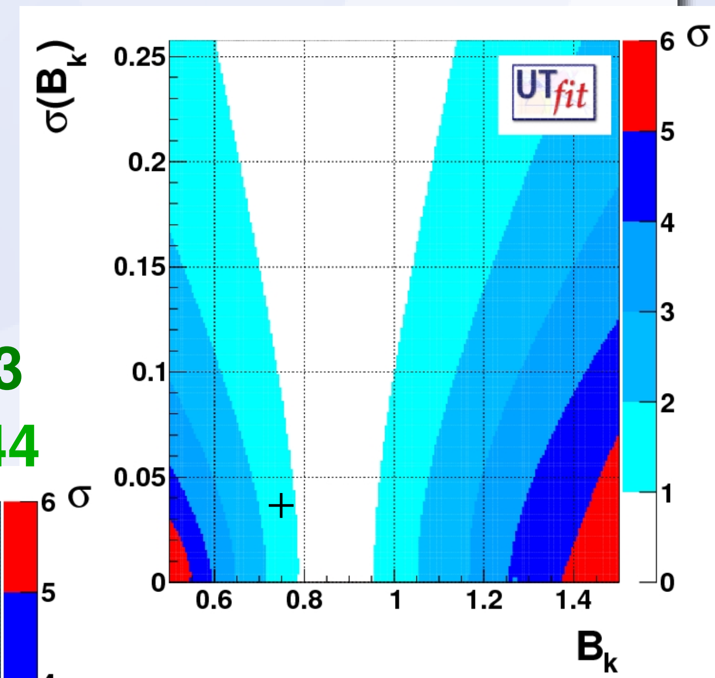
$Vub_{UTfit} = (3.64 \pm 0.13) \cdot 10^{-3}$

~1.5σ

$\sin 2\beta_{exp} = 0.680 \pm 0.023$

$\sin 2\beta_{UTfit} = 0.755 \pm 0.044$

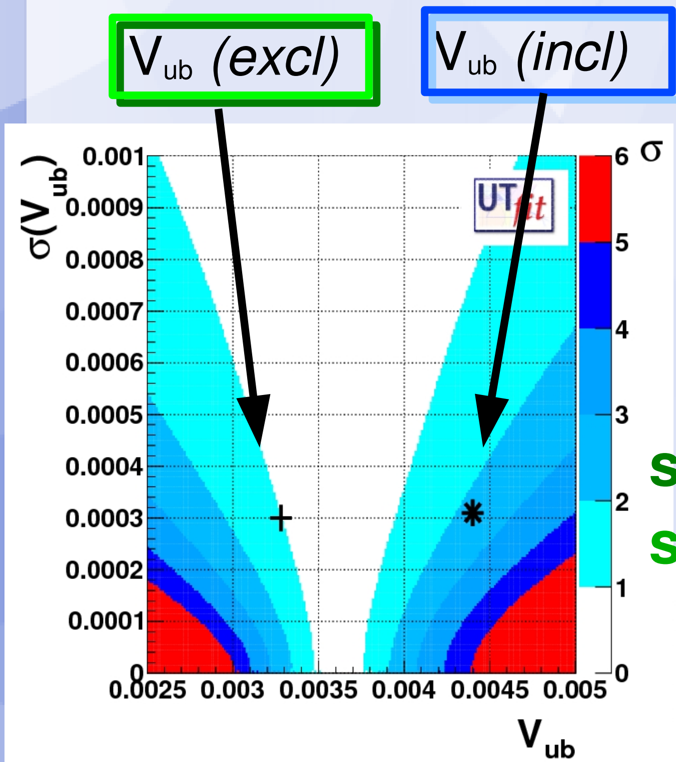




$B_{Kexp} = 0.730 \pm 0.030$

$B_{KUTfit} = 0.866 \pm 0.086$

tensions (or used-to-be tensions)



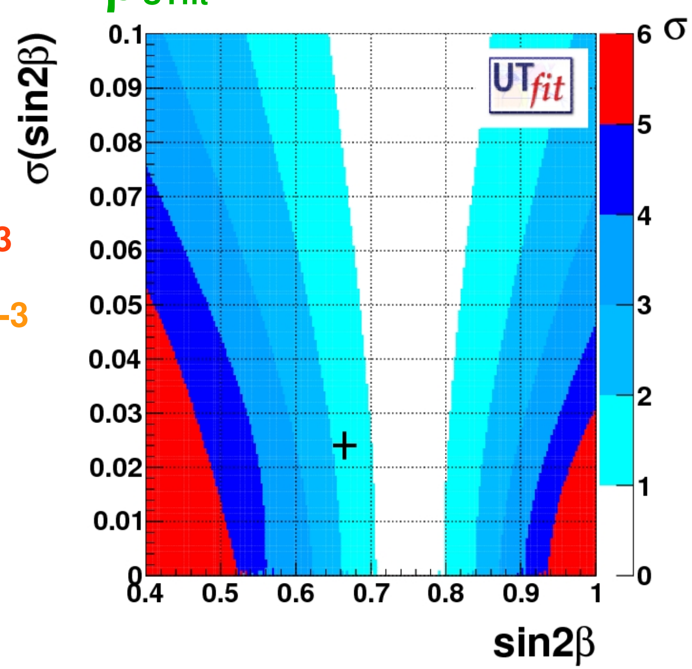
$Vub_{exp} = (3.82 \pm 0.56) \cdot 10^{-3}$

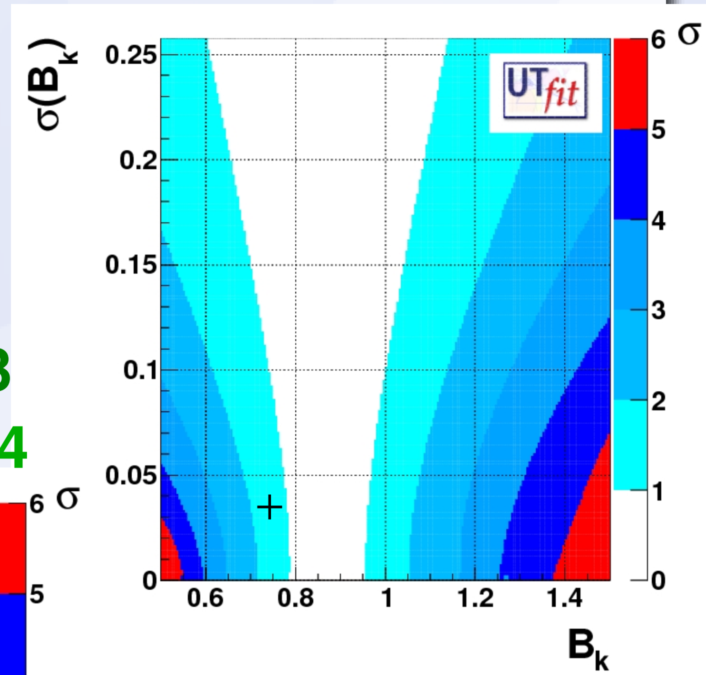
$Vub_{UTfit} = (3.64 \pm 0.13) \cdot 10^{-3}$

~1.5σ

$\sin 2\beta_{exp} = 0.680 \pm 0.023$

$\sin 2\beta_{UTfit} = 0.755 \pm 0.044$

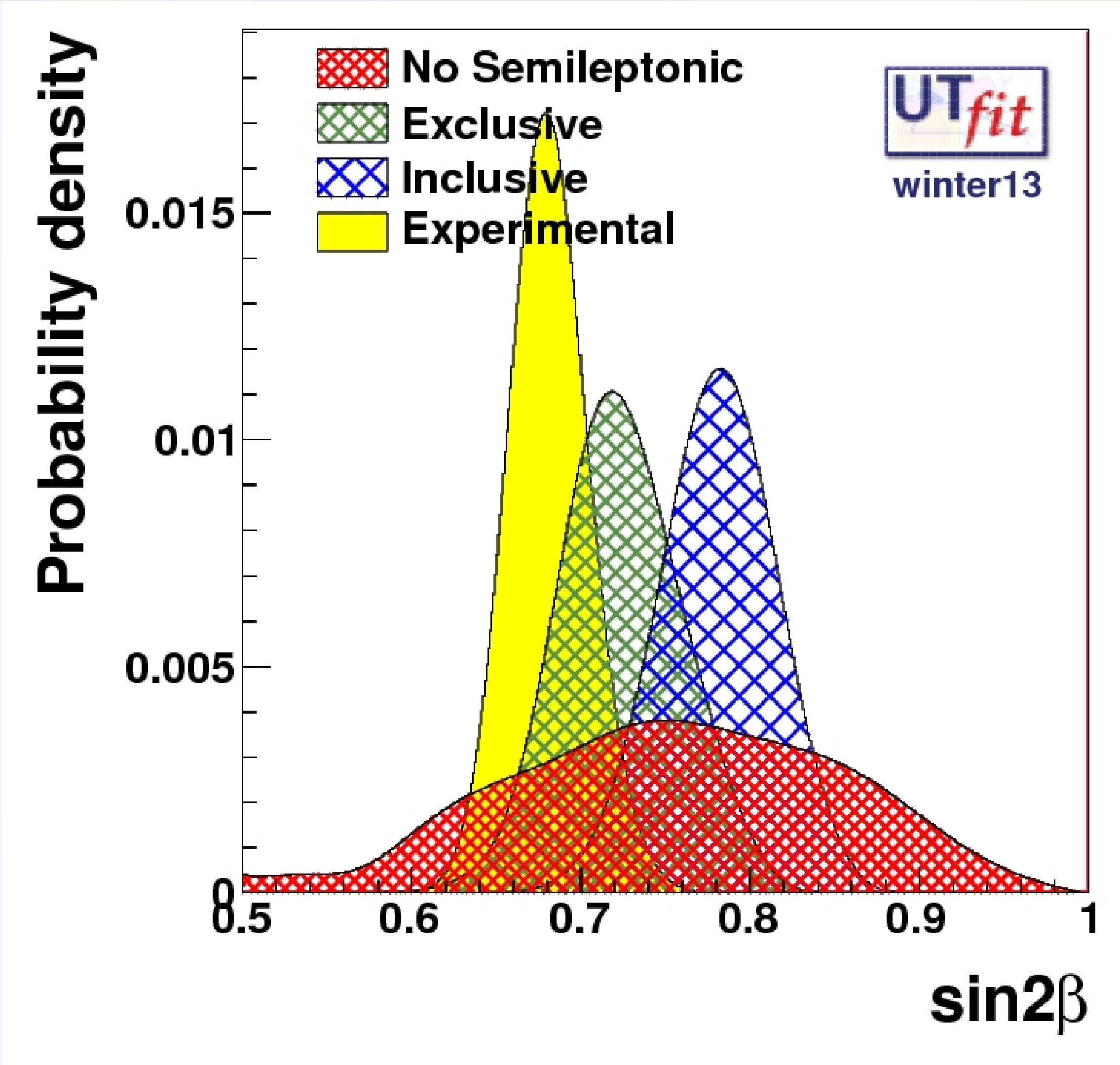




$B_{Kexp} = 0.730 \pm 0.030$

$B_{KUTfit} = 0.866 \pm 0.086$

inclusives vs exclusives



only exclusive values

$\sin 2\beta_{UTfit}$ = 0.723 ± 0.036

~1σ

only inclusive values

$\sin 2\beta_{UTfit}$ = 0.781 ± 0.034

~2.5σ

$\sin 2\beta_{UTfit}$ = 0.76 ± 0.10 ¬ *no semileptonic*

~0.8σ

Unitarity Triangle analysis in the SM:

obtained excluding the given constraint from the fit

Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.680 ± 0.023*	0.755 ± 0.044	~ 1.5
γ	70.8 ± 7.8	68.6 ± 3.6	< 1
α	90.9 ± 8.0	87.7 ± 3.6	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.82 ± 0.56	3.64 ± 0.13	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.40 ± 0.31	–	~ 2.2
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.28 ± 0.30	–	~ 1.1
$\lvert V_{cb}\rvert \cdot 10^3$	41.0 ± 1.0	42.73 ± 0.77	~ 1.3
$\varepsilon_K \cdot 10^3$	2.228 ± 0.011	1.88 ± 0.20	~ 1.7
$BR(B \to \tau\nu)$	0.99 ± 0.25	0.826 ± 0.079	< 1

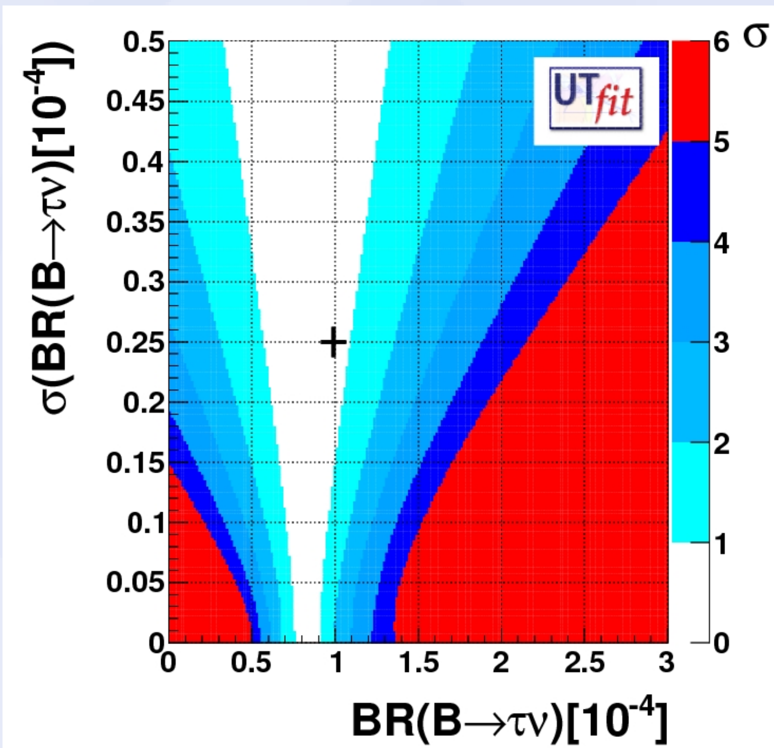
more standard model predictions:

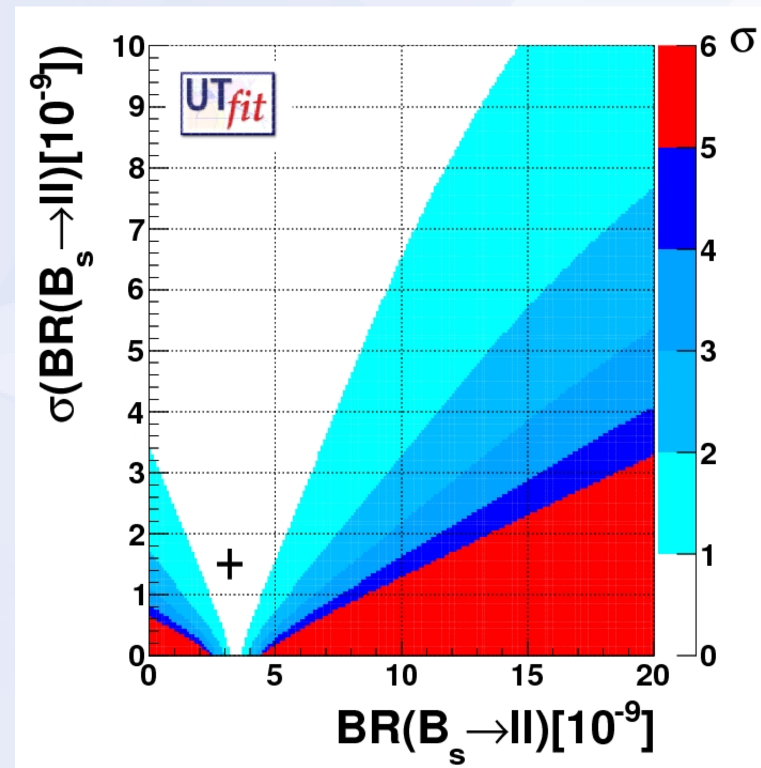
our home-made average:

$BR(B \to \tau\nu) = (0.99 \pm 0.25)\ 10^{-4}$

from LHCb evidence

$BR(B_s \to \mu\mu) = 3.2 \pm 1.5\ 10^{-9}$





indirect determinations from UT

$BR(B \to \tau\nu) = (0.826 \pm 0.079)\ 10^{-4}$

$BR(B_s \to ll) = (3.45 \pm 0.26)\ 10^{-9}$

M.Bona et al, 0908.3470 [hep-ph]

UT analysis including new physics

fit simultaneously for the CKM and the NP parameters (generalized UT fit)

- add most general loop NP to all sectors
- use all available experimental info
- find out NP contributions to ΔF=2 transitions

B_d and B_s mixing amplitudes (2+2 real parameters):

$$A_q = C_{B_q} e^{2i\varphi_{B_q}} A_q^{SM} e^{2i\varphi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\varphi_q^{NP} - \varphi_q^{SM})}\right) A_q^{SM} e^{2i\varphi_q^{SM}}$$

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM}$$

$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right)$$

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_s \to J/\psi \phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

$$\Delta \Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

new-physics-specific constraints

$$A^s_{\rm SL} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \mathrm{Im}\left(\frac{\Gamma^s_{12}}{A^{\rm full}_s}\right)$$

semileptonic asymmetries:
sensitive to NP effects in both size and phase
2D constraints a la HFAG for A^s_{sl} and A^d_{sl}

CDF + D0 + LHCb

same-side dilepton charge asymmetry:
admixture of B_s and B_d so sensitive to NP effects in both systems

D0 arXiv:1106.6308

$$A^{\mu\mu}_{\rm SL} \times 10^3 = -7.9 \pm 2.0$$

$$A^{\mu\mu}_{\rm SL} = \frac{f_d \chi_{d0} A^d_{\rm SL} + f_s \chi_{s0} A^s_{\rm SL}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

lifetime τ^{FS} in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)

$$\tau^{\rm FS}_{B_s}\ [\mathrm{ps}] = 1.417 \pm 0.042$$

HFAG

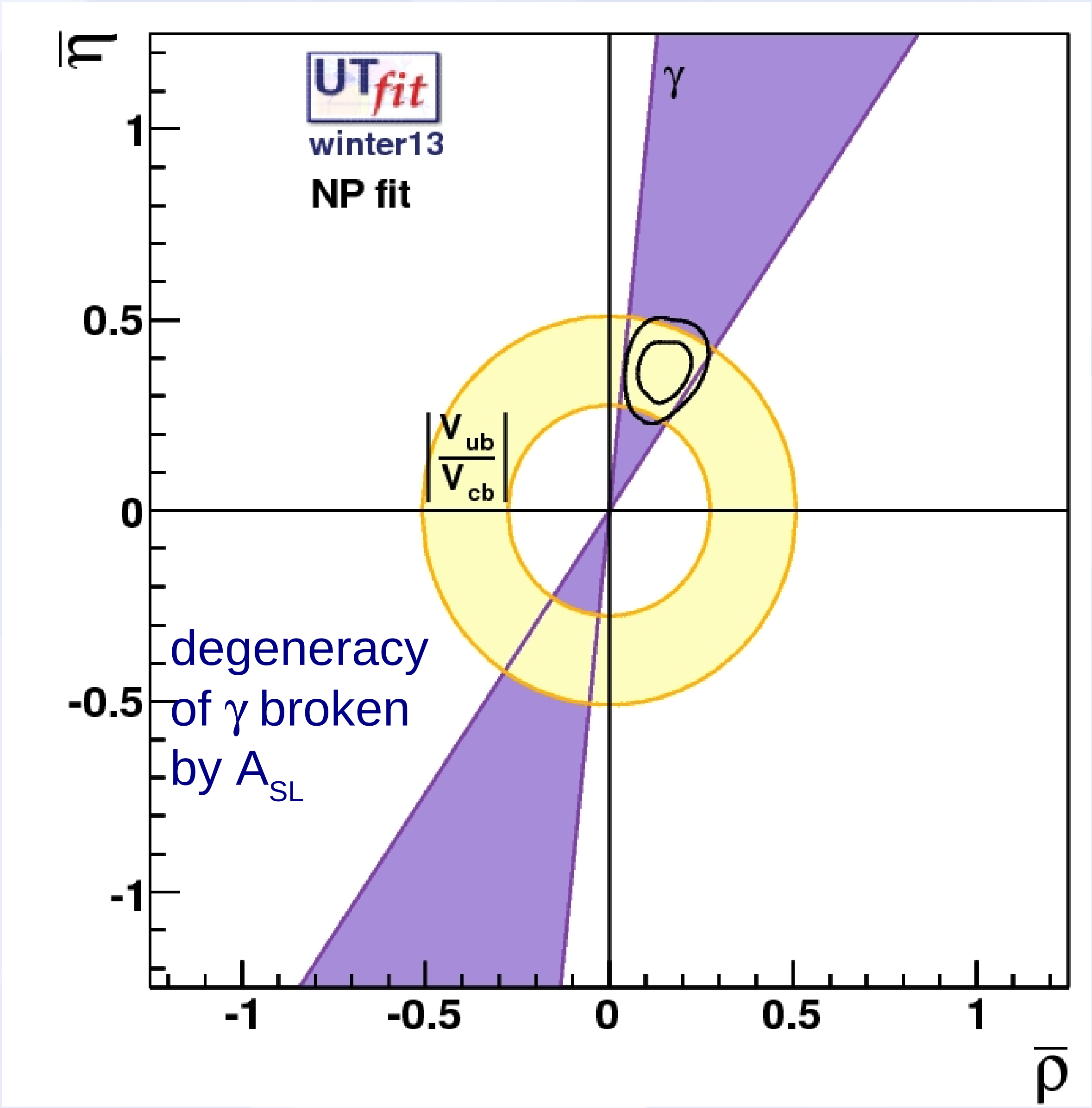
$$\tau^{FS}_{B_s} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

angular analysis as a function of proper time and b-tagging. Additional sensitivity from the $\Delta\Gamma_s$ terms

CDF + D0: 2D likelihood
LHCb: Gaussian

NP analysis results



$\bar{\rho} = 0.147 \pm 0.048$

$\bar{\eta} = 0.370 \pm 0.057$

SM is

$\bar{\rho} = 0.132 \pm 0.021$

$\bar{\eta} = 0.350 \pm 0.014$

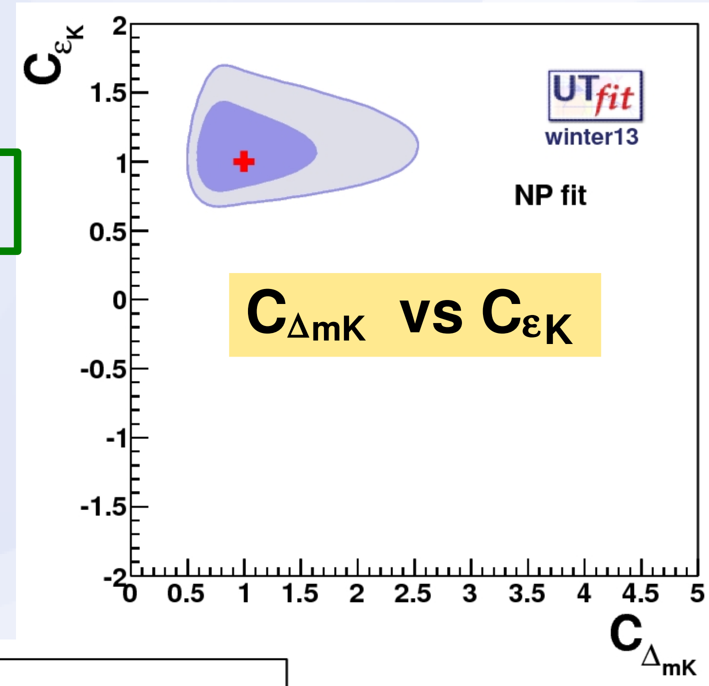
NP parameter results

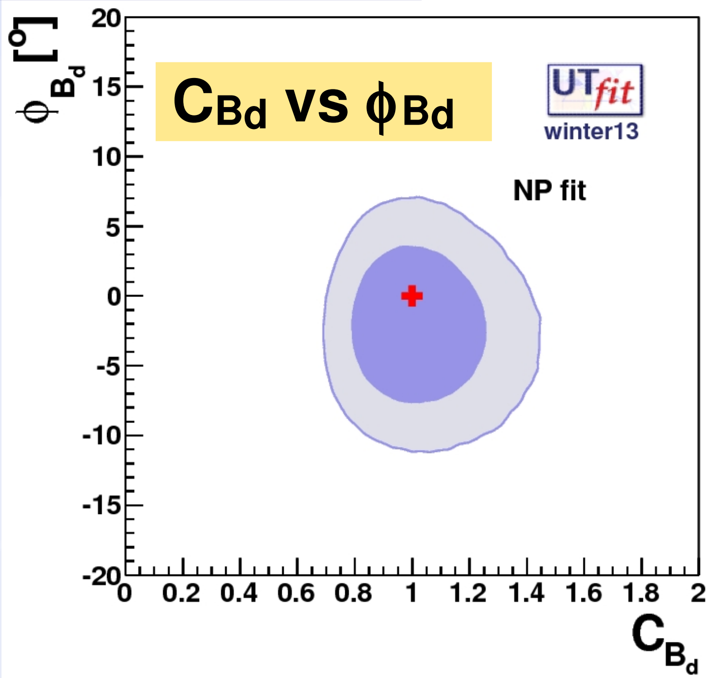
dark: 68%
light: 95%
SM: red cross

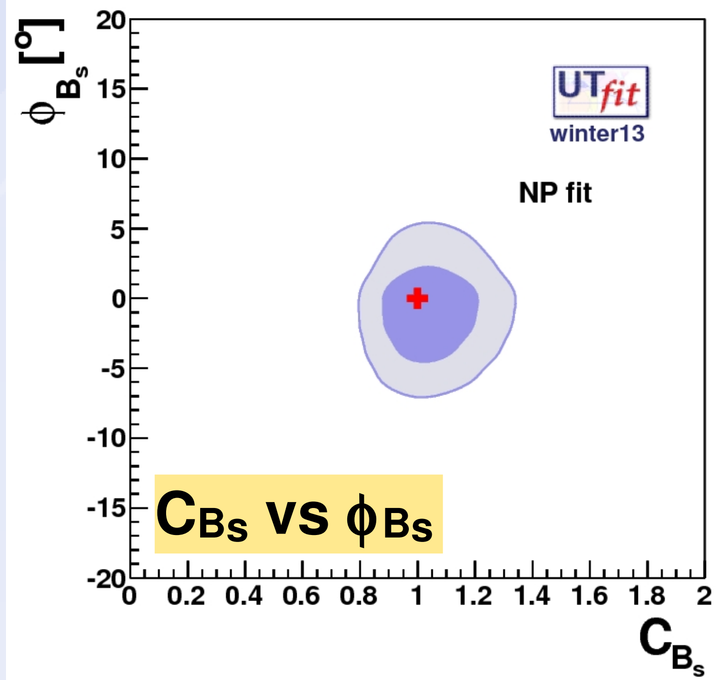
$C_{\varepsilon_K} = 1.08 \pm 0.18$

$C_{B_d} = 1.01 \pm 0.15$
$\phi_{B_d} = (-2.2 \pm 3.7)°$

$$A_q = C_{B_q} e^{2i\varphi_{B_q}} A_q^{SM} e^{2i\varphi_q^{SM}}$$



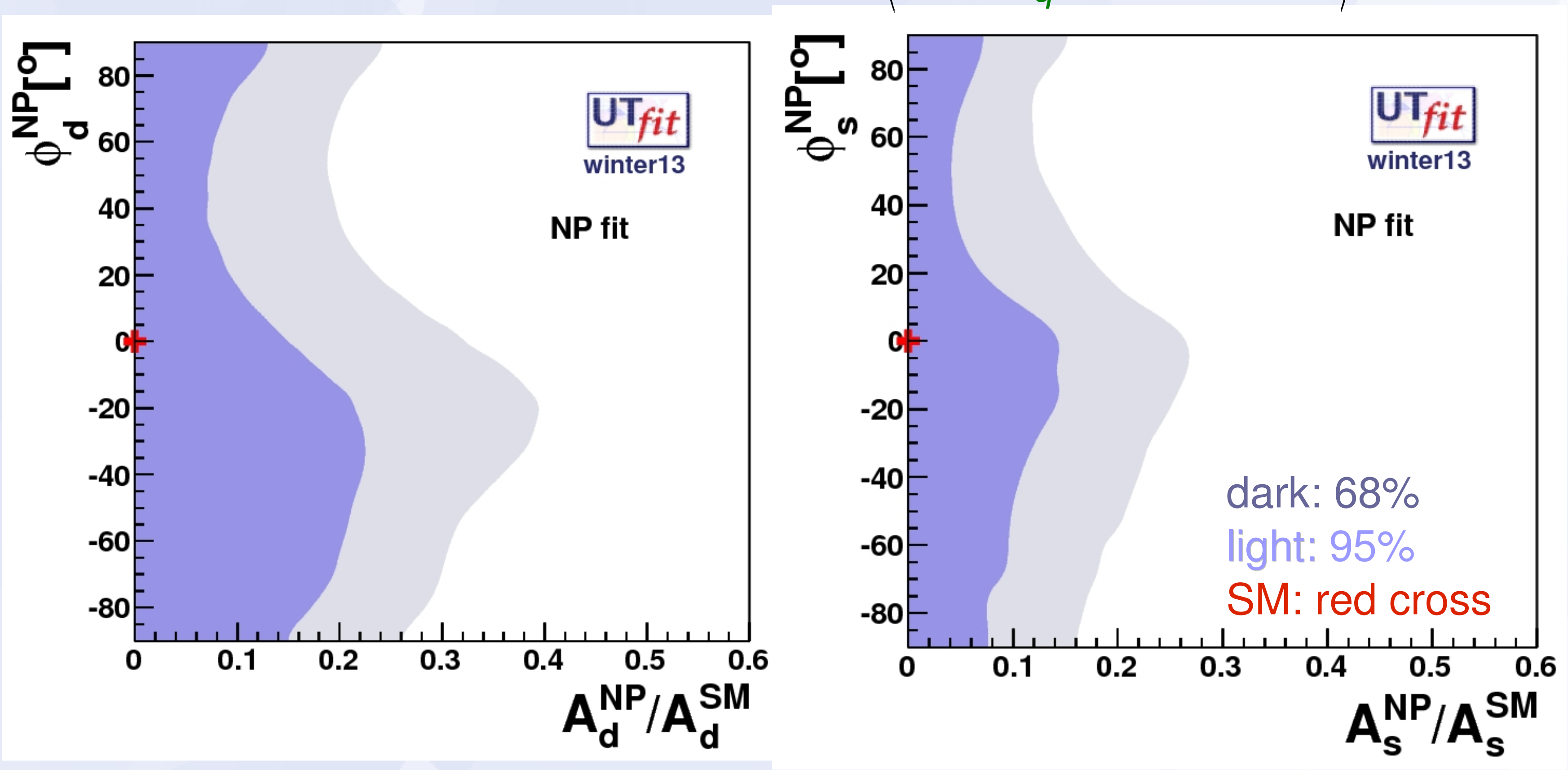




$C_{B_s} = 1.03 \pm 0.10$
$\phi_{B_s} = (-0.8 \pm 2.5)°$

NP parameter results

$$A_q = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\varphi_q^{NP} - \varphi_q^{SM})}\right) A_q^{SM} e^{2i\varphi_q^{SM}}$$



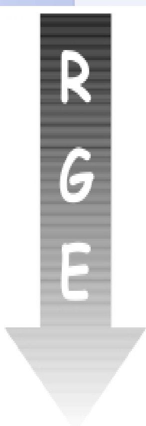
The ratio of NP/SM amplitudes is:

< 20% @68% prob. (35% @95%) in B_d mixing

< 15% @68% prob. (25% @95%) in B_s mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.

testing the new-physics scale



At the high scale

new physics enters according to its specific features

At the low scale

use OPE to write the most general effective Hamiltonian.
the operators have different chiralities than the SM
NP effects are in the Wilson Coefficients C

$$\mathcal{H}_{\rm eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta}\,,\\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta}\,,\\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha}\,,\\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta}\,,\\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha}\,.
\end{aligned}$$

NP effects are enhanced

- up to a factor 10 by the values of the matrix elements especially for transitions among quarks of different chiralities
- up to a factor 8 by RGE

M. Bona *et al.* (UTfit)
JHEP 0803:049,2008
arXiv:0707.0636

effective BSM Hamiltonian for ΔF=2 transitions

The Wilson coefficients C_i have in general the form

$$C_i(\Lambda) = F_i \frac{L_i}{\Lambda^2}$$

Putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios that enter through F_i and L_i

F_i: function of the NP flavour couplings
L_i: loop factor (in NP models with no tree-level FCNC)
Λ: NP scale (typical mass of new particles mediating ΔF=2 transitions)

testing the TeV scale

$$C_i(\Lambda) = F_i \frac{L_i}{\Lambda^2}$$

The dependence of C on Λ changes on flavor structure.
We can consider different flavour scenarios:

- Generic: $C(\Lambda) = \alpha/\Lambda^2$ $F_i \sim 1$, arbitrary phase
- NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_i \sim |F_{SM}|$, arbitrary phase
- MFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_1 \sim |F_{SM}|$, $F_{i\neq 1} \sim 0$, SM phase

α (L_i) is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_S) in case of loop coupling through weak (strong) interactions

If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

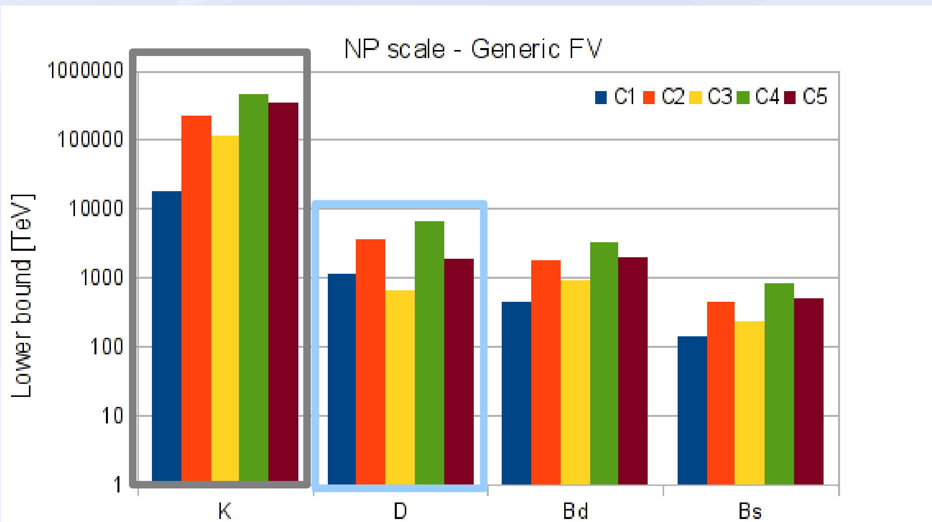
F is the flavour coupling and so
F_{SM} is the combination of CKM factors for the considered process

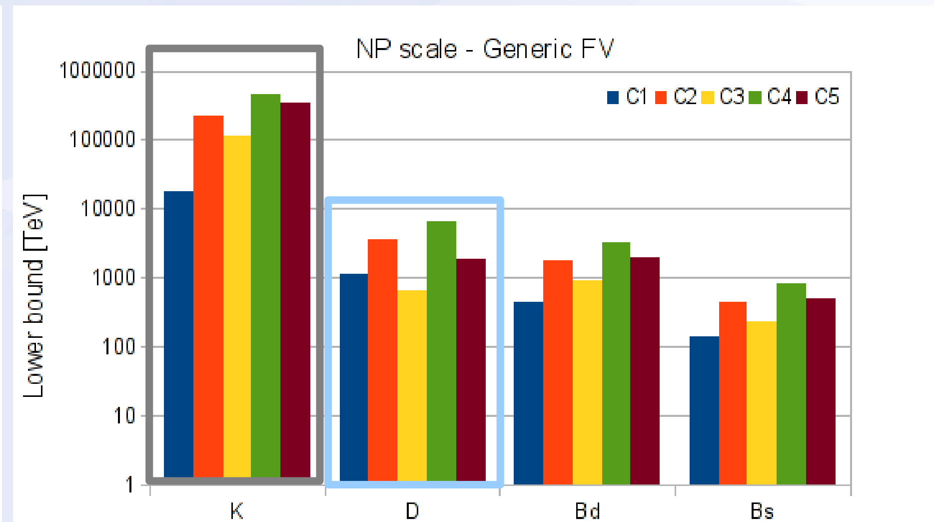
results from the Wilson coefficients

Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP

- $\alpha \sim \alpha_W$ in case of loop coupling through weak interactions





Lower bounds on NP scale (in TeV at 95% prob.)

Non-perturbative NP

$\Lambda > 4.6\ 10^5$ TeV

[6.7 10^3 TeV from D's]

NP in α_W loops

$\Lambda > 1.4\ 10^4$ TeV

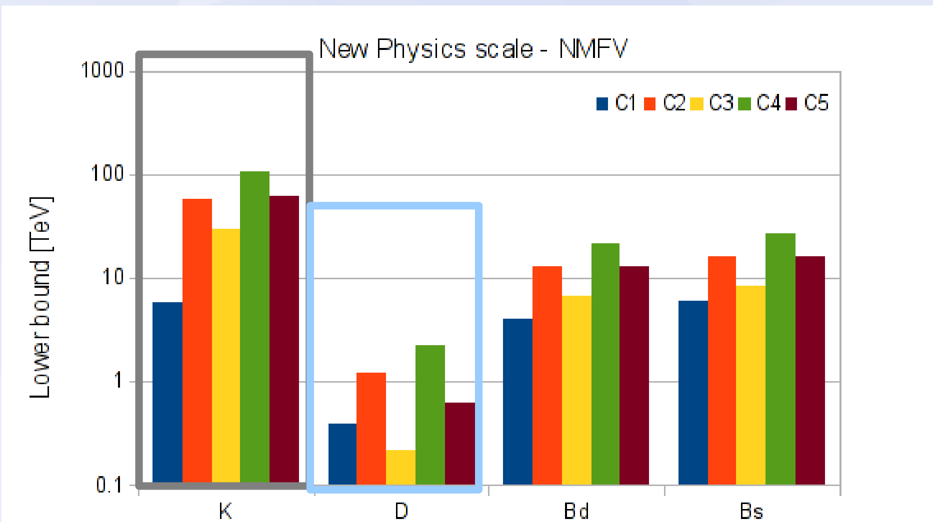
[202 TeV from D's]

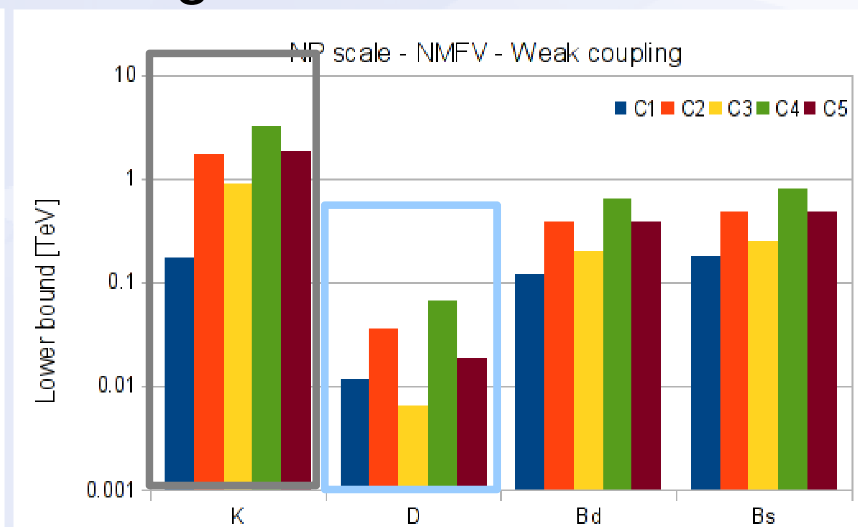
results from the Wilson coefficients

NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$, $F_i \sim |F_{SM}|$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP

• $\alpha \sim \alpha_W$ in case of loop coupling through weak interactions





Lower bounds on NP scale (in TeV at 95% prob.)

Non-perturbative NP
$\Lambda > 105$ TeV
(2.2 TeV from D's)

NP in α_W loops
$\Lambda > 3.2$ TeV
(0.07 TeV from D's)

The future of CKM fits

LHCb reach from:
O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from:
SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015 10/fb (5 years)	SuperB 1/ab (1 month at Y(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s ($J/\psi\ \phi$)	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ ($J/\psi\ K_s$)	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%

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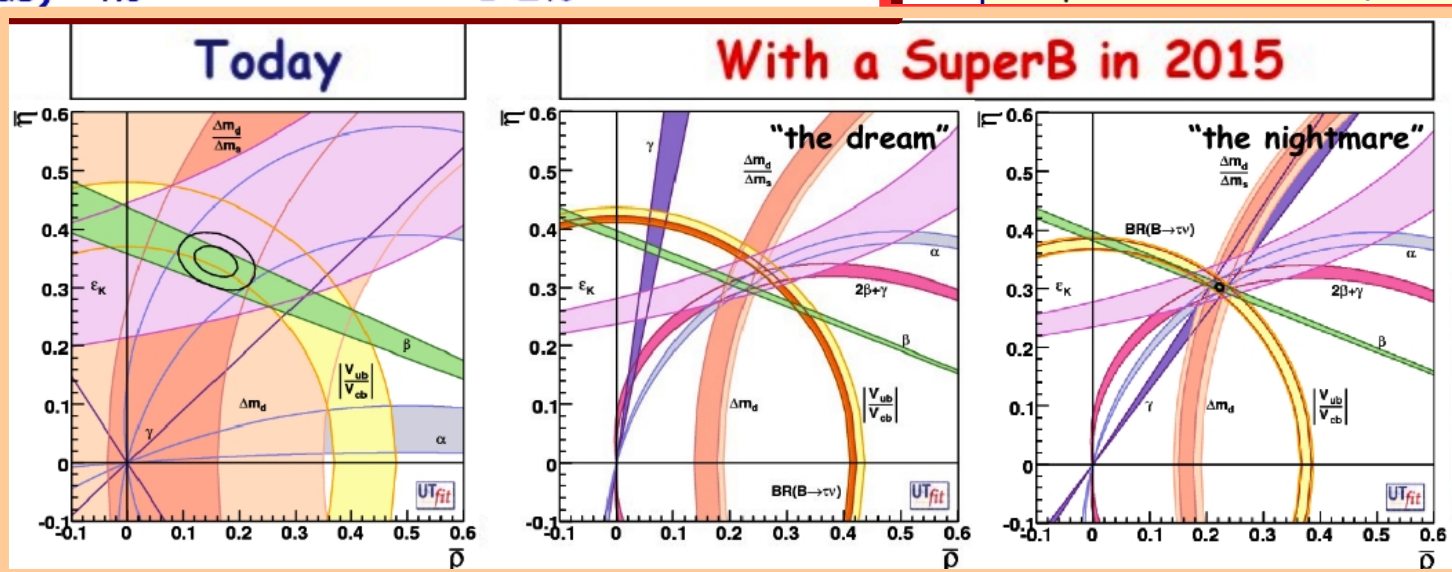
Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s}B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

S. Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee



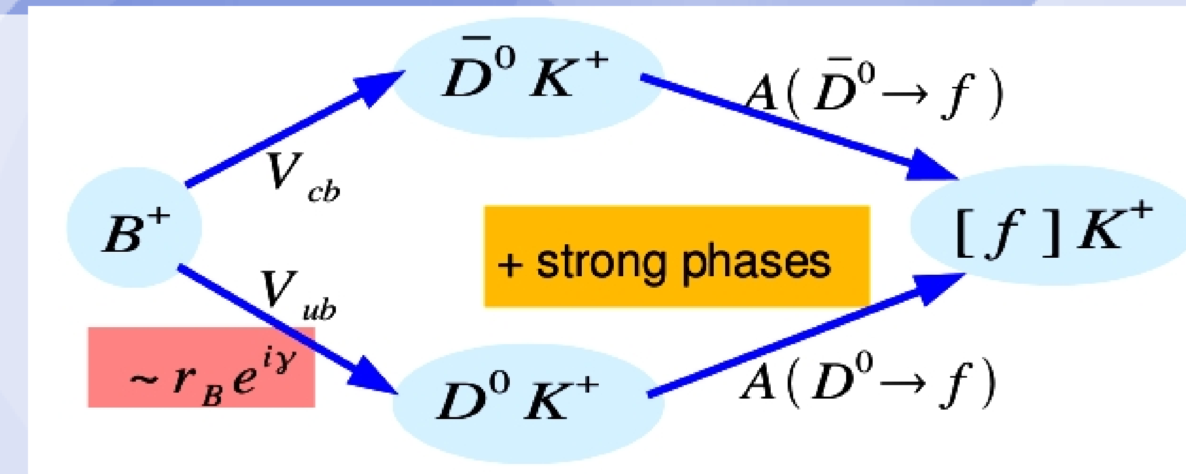
conclusions

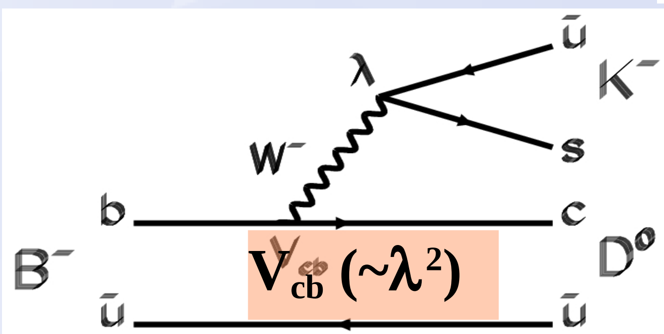
- SM analysis displays very good overall consistency
- Still open discussion on semileptonic inclusive vs exclusive
- UTA provides determination also of NP contributions to $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 15-20%
- So the scale analysis points to high scales for the generic scenario and even above LHC reach for weak coupling. Indirect searches become essential.
- Even if we don't see relevant deviations in the down sector, we might still find them in the up sector.

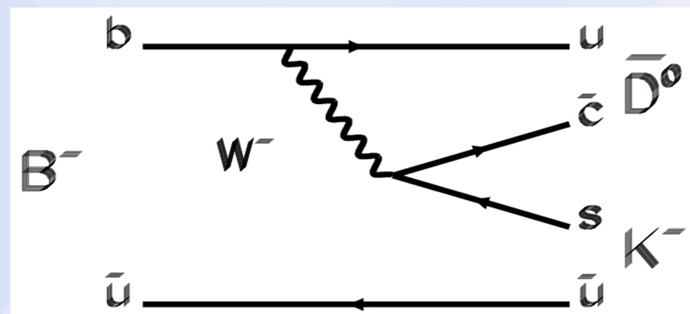
Back up slides

γ and DK trees

$B \to D^{(*)0}(\bar{D}^{(*)0})K^{(*)}$ decays can proceed both through V_{cb} and V_{ub} amplitudes







$V_{ub} = |V_{ub}| e^{-i\gamma}$ $(\sim\lambda^3)$

δ_B = strong phase diff.

$$A(B^- \to D^0 K^-) = A_B$$
$$A(B^+ \to \bar{D}^0 K^+) = A_B$$

$$A(B^- \to \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)}$$
$$A(B^+ \to D^0 K^+) = A_B r_B e^{i(\delta_B + \gamma)}$$

sensitivity to γ: the amplitude ratio r_B

$$r_B = \left| \frac{B^- \to \bar{D}^0 K^-}{B^- \to D^0 K^-} \right| = \sqrt{\bar{\eta}^2 + \bar{\rho}^2} \times F_{CS}$$

hadronic contribution channel-dependent

γ and DK trees

- GLW(*Gronau, London, Wyler*) method: uses the CP eigenstates $D^{(*)0}_{CP}$ with final states: K^+K^-, $\pi^+\pi^-$ (CP-even), $K_s\pi^0$ (ω,ϕ) (CP-odd)

$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B \qquad A_{CP\pm} = \frac{\pm 2r_B \sin\gamma \sin\delta_B}{1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B}$$

- ADS(*Atwood, Dunietz, Soni*) method: B^0 and $\bar{B}^0$ in the same final state with $D^0 \to K^+\pi^-$ (suppr.) and $\bar{D}^0 \to K^+\pi^-$ (fav.)

$$R_{ADS} = r_B^2 + r_{DCS}^2 + 2r_B r_{DCS} \cos\gamma \cos(\delta_B + \delta_D)$$

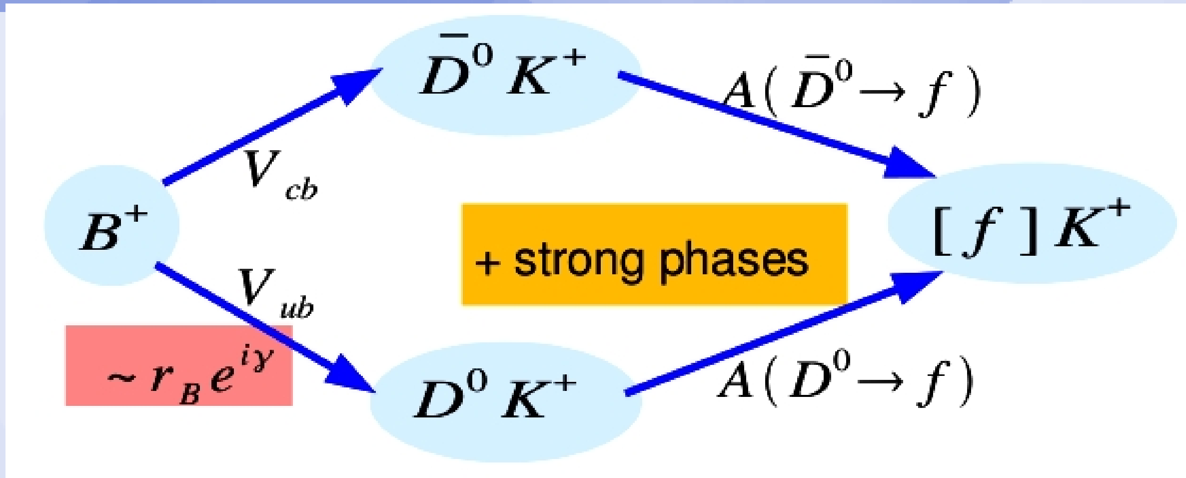
more sensitive to r_B

- D^0 Dalitz plot with the decays $B^- \to D^{(*)0}[K_S\pi^+\pi^-]\, K^-$

the most sensitive way to γ

three free parameters to extract: γ , r_B and δ_B

γ and DK trees



model dependence from D dalitz

Belle and LHCb has a model independent dalitz analysis (still relatively higher errors)

CP violation in charm

will need to be considered as

LHCb and Belle II expect to have uncertainty at the level of ~1°

UT analysis including NP

	ρ, η	C_{Bd}, ϕ_{Bd}	$C_{\varepsilon K}$	C_{bs}, ϕ_{Bs}
V_{ub}/V_{cb}	X			
γ (DK)	X			
ε_K	X		X	
$\sin 2\beta$	X	X		
Δm_d	X	X		
α	X	X		
A_{SL} B_d	X	X X		
$\Delta\Gamma_d/\Gamma_d$	X	X X		
$\Delta\Gamma_s/\Gamma_s$	X			X X
Δm_s				X
A_{CH}	X	X X		X X

model independent assumptions

SM	SM+NP
tree level	
$(V_{ub}/V_{cb})^{SM}$	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}	γ^{SM}
Bd Mixing	
β^{SM}	$\beta^{SM}+\phi_{Bd}$
α^{SM}	$\alpha^{SM}-\phi_{Bd}$
Δm_d	$C_{Bd}\Delta m_d$
Bs Mixing	
Δm_s^{SM}	$C_{Bs}\Delta m_s^{SM}$
β_s^{SM}	$\beta_s^{SM}+\phi_{Bs}$
K Mixing	
ε_K^{SM}	$C\varepsilon_K\ \varepsilon_K^{SM}$

new-physics-specific constraints

$$A^s_{\mathrm{SL}} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \mathrm{Im}\left(\frac{\Gamma^s_{12}}{A^{\mathrm{full}}_s}\right)$$

Laplace et al. Phys.Rev.D 65: 094040,2002

semileptonic asymmetries:
sensitive to NP effects in both size and phase
2D constraints a la HFAG for A^s_{sl} and A^d_{sl}

CDF + D0 + LHCb

same-side dilepton charge asymmetry:
admixture of B_s and B_d so sensitive to NP effects in both systems

$$A^{\mu\mu}_{\mathrm{SL}} \times 10^3 = -7.9 \pm 2.0$$

D0 arXiv:1106.6308

$$A^{\mu\mu}_{\mathrm{SL}} = \frac{f_d \chi_{d0} A^d_{\mathrm{SL}} + f_s \chi_{s0} A^s_{\mathrm{SL}}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

new-physics-specific constraints

$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

Dunietz et al., hep-ph 0012219

lifetime τ^{FS} in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)

$$\tau_{B_s}^{\mathrm{FS}}\ [\mathrm{ps}] = 1.417 \pm 0.042$$ HFAG

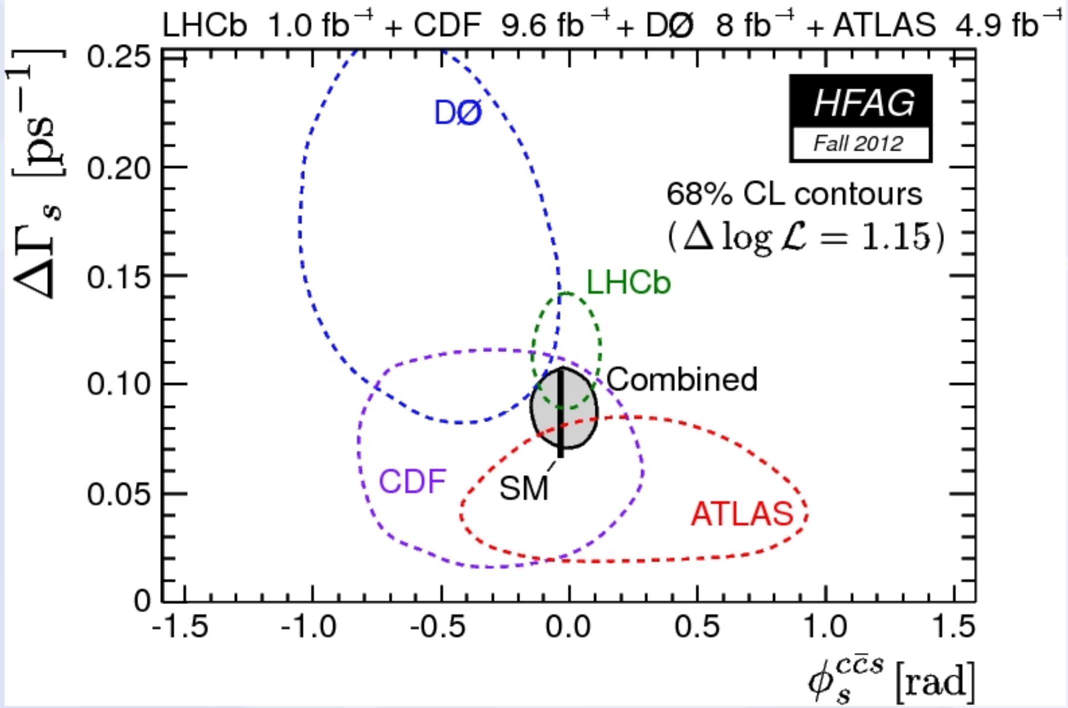
$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

angular analysis as a function of proper time and b-tagging
additional sensitivity from the $\Delta\Gamma_s$ terms

ϕ_s and $\Delta\Gamma_s$:
2D experimental likelihood from CDF and D0

ϕ_s and $\Delta\Gamma_s$:
central values with gaussian errors from LHCb

new-physics-specific constraints



$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \rightarrow J/\psi\phi$

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gaussian errors from LHCb

new-physics-specific constraints

B meson mixing matrix element NLO calculation
Ciuchini et al. JHEP 0308:031,2003.

$$
\begin{aligned}
\frac{\Gamma^q_{12}}{A^{\rm full}_q} = -2\frac{\kappa}{C_{B_q}}\Bigg\{ & e^{2\phi_{B_q}}\left(n_1+\frac{n_6 B_2+n_{11}}{B_1}\right)-\frac{e^{(\phi_q^{\rm SM}+2\phi_{B_q})}}{R_t^q}\left(n_2+\frac{n_7 B_2+n_{12}}{B_1}\right) \\
& +\frac{e^{2(\phi_q^{\rm SM}+\phi_{B_q})}}{R_t^{q^2}}\left(n_3+\frac{n_8 B_2+n_{13}}{B_1}\right)+e^{(\phi_q^{\rm Pen}+2\phi_{B_q})}C_q^{\rm Pen}\left(n_4+n_9\frac{B_2}{B_1}\right) \\
& -e^{(\phi_q^{\rm SM}+\phi_q^{\rm Pen}+2\phi_{B_q})}\frac{C_q^{\rm Pen}}{R_t^q}\left(n_5+n_{10}\frac{B_2}{B_1}\right)\Bigg\}
\end{aligned}
$$

C_{pen} and ϕ_{pen} are parameterize possible NP contributions from $b \to s$ penguins

$\phi_s=2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

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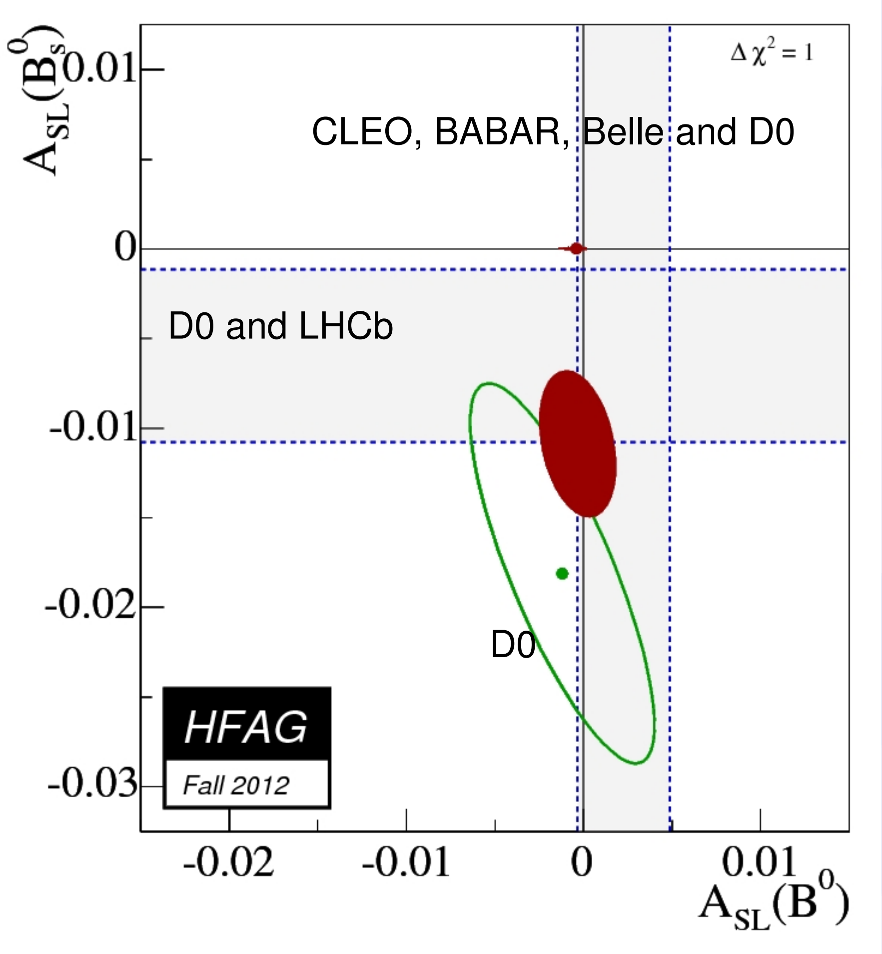
ϕ_s and $\Delta\Gamma_s$:
central values with gaussian errors from LHCb

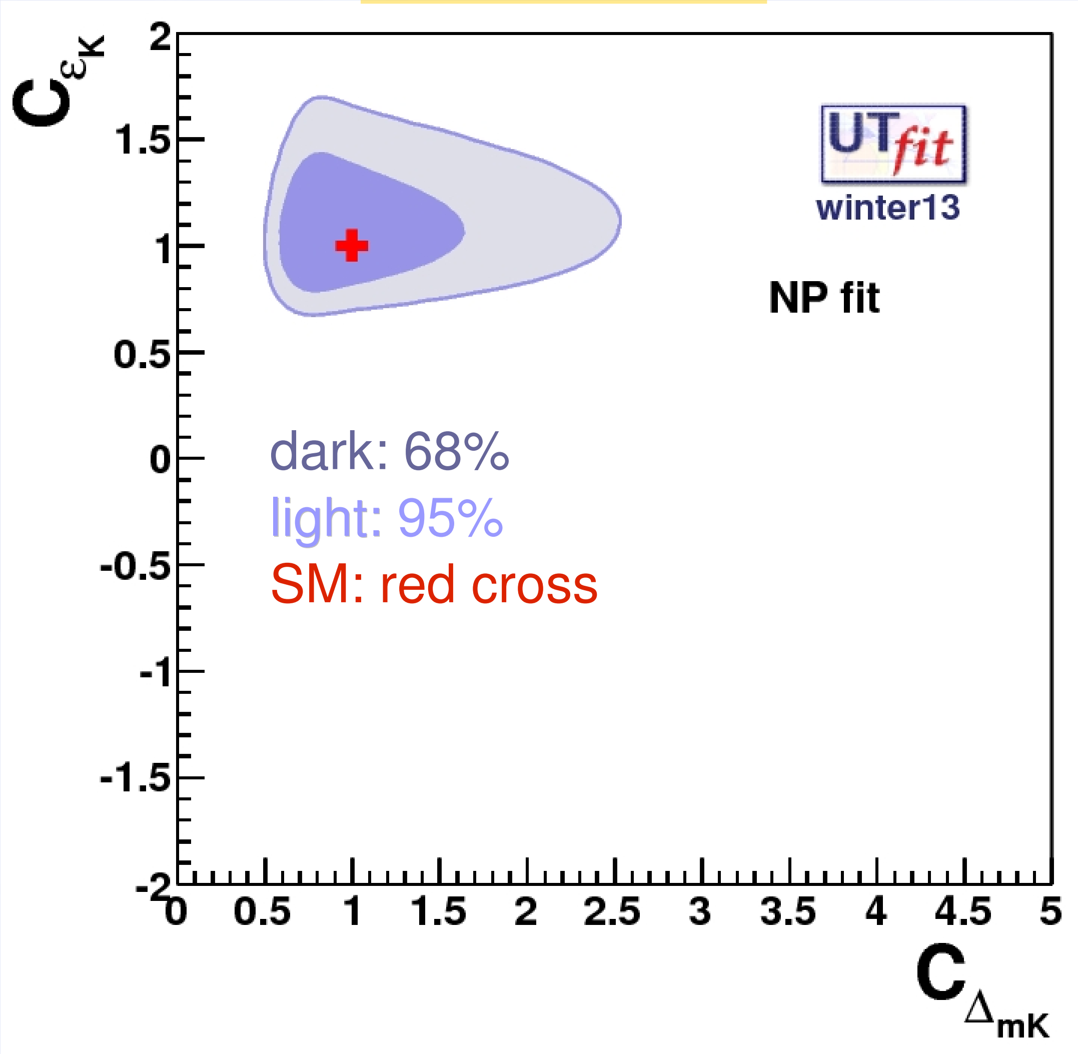
new-physics-specific constraints

semileptonic asymmetries



NP parameter results

$C_{\Delta mK}$ vs $C_{\varepsilon K}$



$C_{\varepsilon_K} = 1.08 \pm 0.18$

$C_{\Delta mK} = 0.98 \pm 0.33$

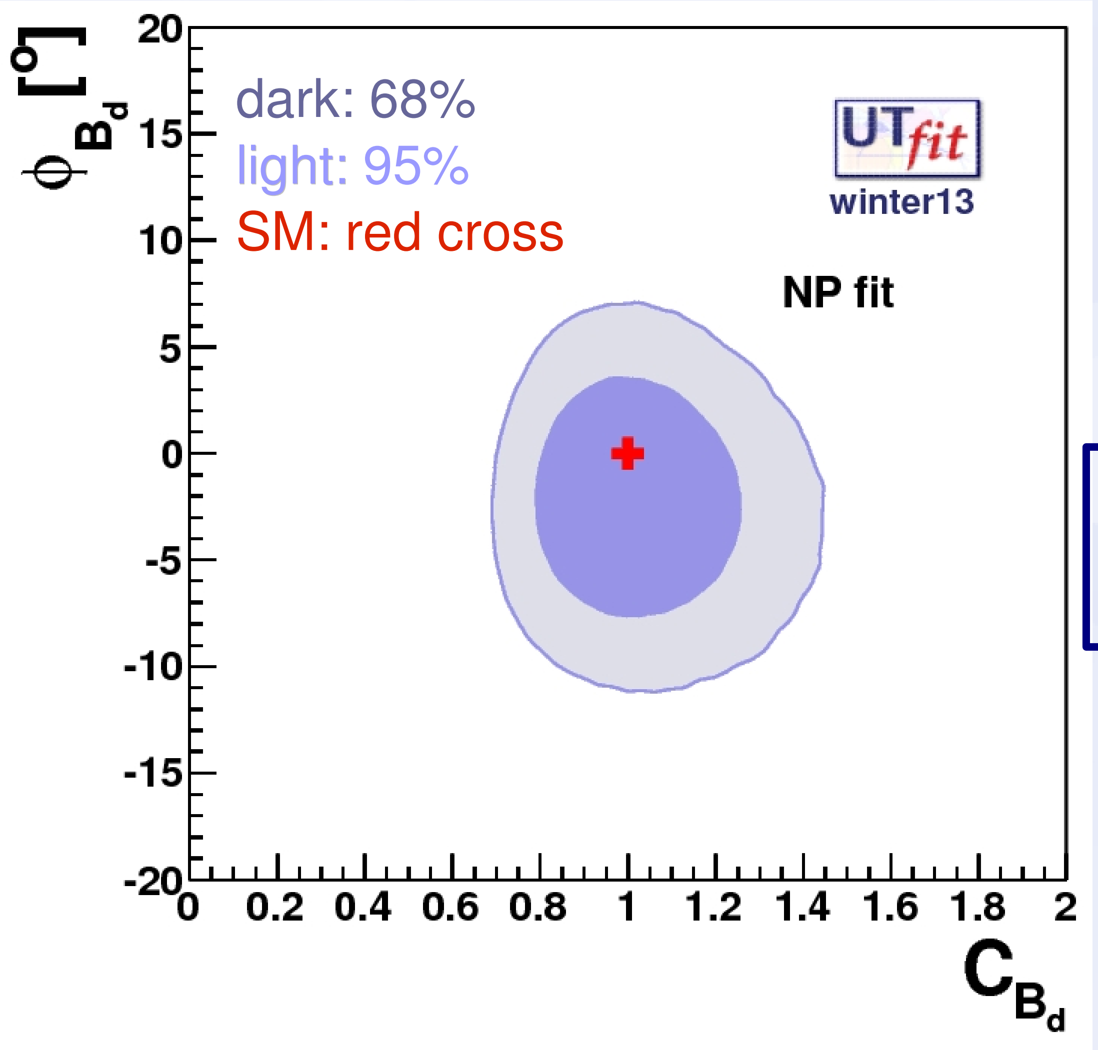
$$\mathrm{Im}\, A_K = C_{\varepsilon}\, \mathrm{Im}\, A_K^{SM}$$
$$\mathrm{Re}\, A_K = C_{\Delta m_K}\, \mathrm{Re}\, A_K^{SM}$$

$$\Delta m_K = C_{\Delta m_K} (\Delta m_K)^{SM}$$
$$\varepsilon_K = C_{\varepsilon}\, \varepsilon_K^{SM}$$

NP parameter results

$$C_{B_q}\, e^{2i\phi_{B_q}} = \frac{\langle B_q|H_{\rm eff}^{\rm full}|\bar{B}_q\rangle}{\langle B_q|H_{\rm eff}^{\rm SM}|\bar{B}_q\rangle}$$

C_{B_d} vs ϕ_{B_d}



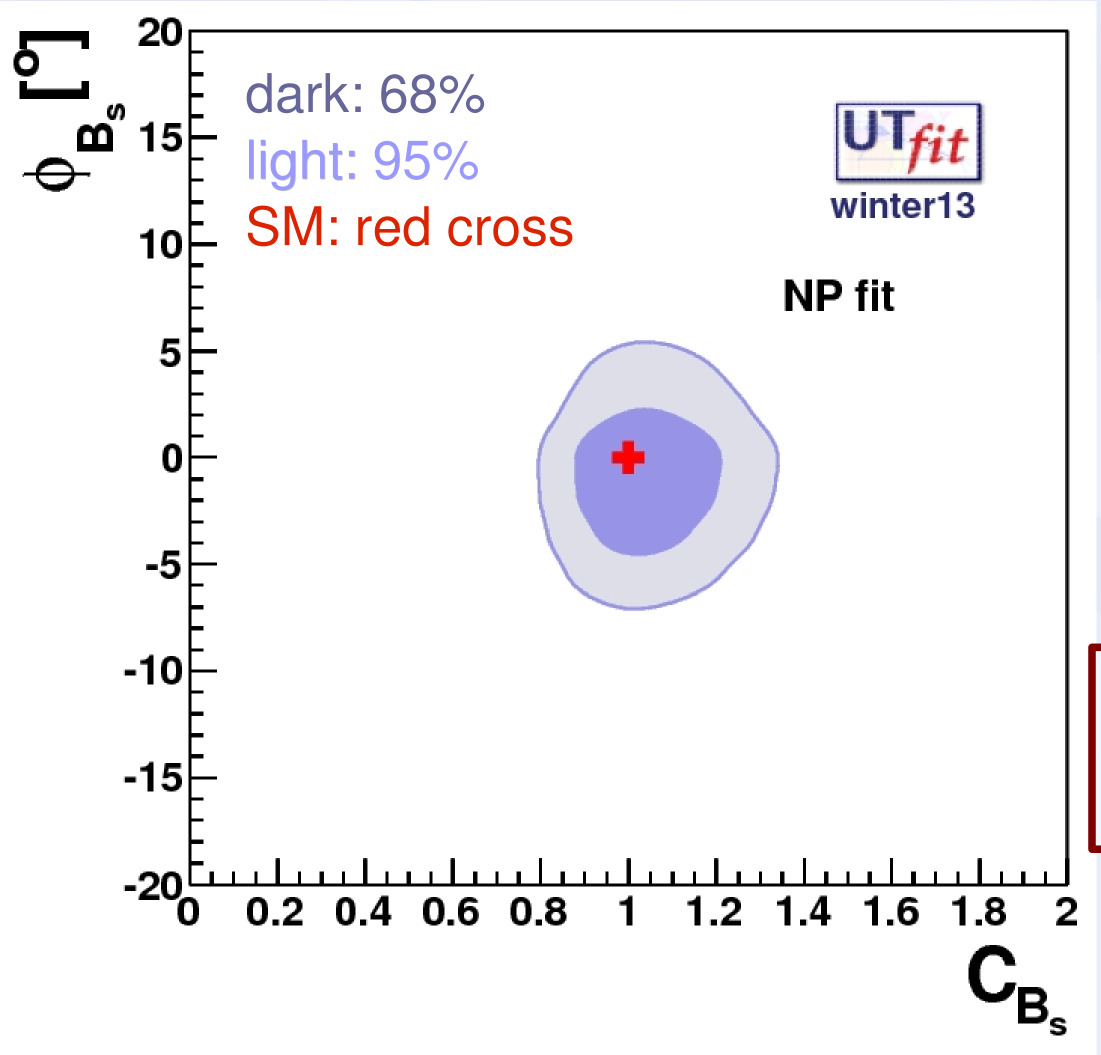
$C_{B_d} = 1.01 \pm 0.15$

$\phi_{B_d} = (-2.2 \pm 3.7)°$

NP parameter results

$$C_{B_q}\, e^{2i\phi_{B_q}} = \frac{\langle B_q | H_{\mathrm{eff}}^{\mathrm{full}} | \bar{B}_q \rangle}{\langle B_q | H_{\mathrm{eff}}^{\mathrm{SM}} | \bar{B}_q \rangle}$$

C_{B_s} vs ϕ_{B_s}



$C_{B_s} = 1.03 \pm 0.10$

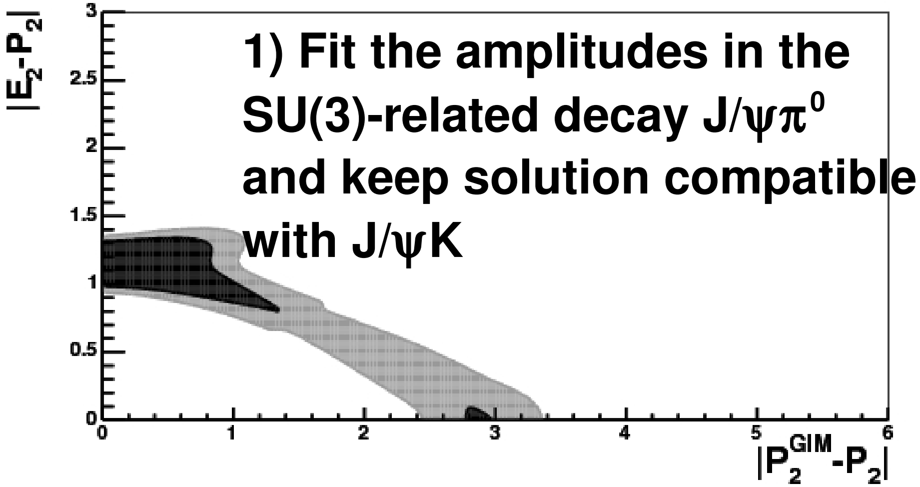
$\phi_{B_s} = (-1.1 \pm 2.2)^\circ$

Theory error on sin2β:

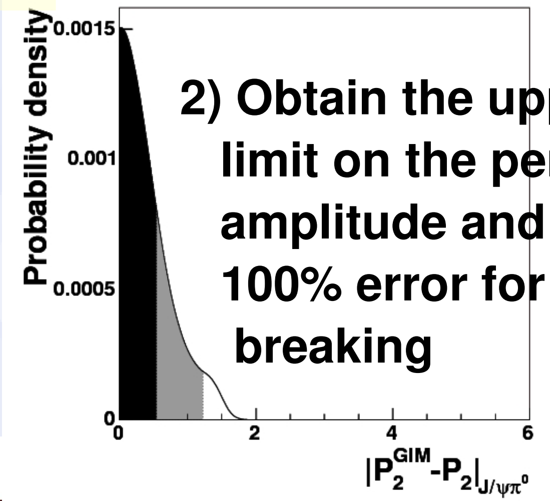
A.Buras, L.Silvestrini
Nucl.Phys.B569:3-52(2000)

Channel	Cl.	E_1	E_2	EA_2	A_2	P_1	P_2	P_3	P_1^{GIM}	P_2^{GIM}	P_3^{GIM}	P_4	P_4^{GIM}
	$V^*_{cb}V_{cs}$		$\frac{1}{N}$	$\frac{1}{N^2}$	$\frac{1}{N}$	$\frac{1}{N}$	$\frac{1}{N^2}$	$V^*_{tb}V_{ts}$	$\frac{1}{N}$	$\frac{1}{N^2}$	$V^*_{ub}V_{us}$	$\frac{1}{N^3}$	$\frac{1}{N^3}$
$B_d \to J/\psi K^0$	C	–	λ^2	–	–	–	λ^2	–	–	λ^4	–	–	–
$B_d \to \pi^0 J/\psi$	D	–	λ^3	λ^3	–	–	λ^3	–	–	λ^3	–	$[\lambda^3]$	$[\lambda^3]$

$V^*_{cb}V_{cd}$ $V^*_{tb}V_{td}$ $V^*_{ub}V_{ud}$

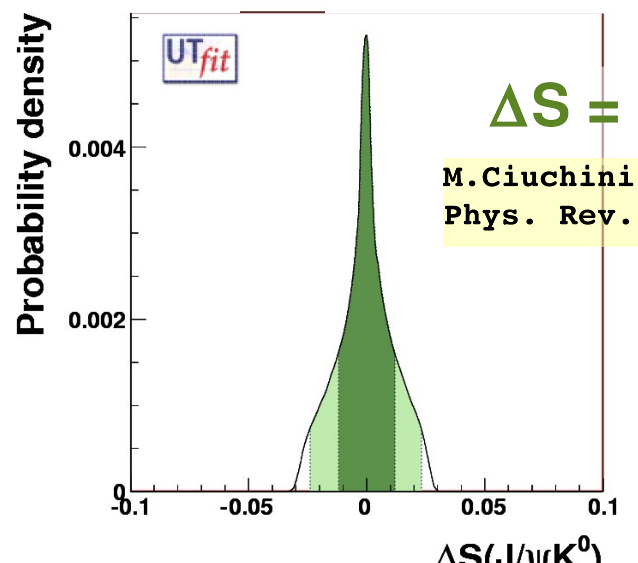


1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β



$\Delta S = 0.000 \pm 0.012$

M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)